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Evaluation of Test Methods To Determine the Impact Resistance of Exterior Insulation and Finish Systems (EIFS)

by
Richard G. Lampo
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FOREWORD

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This work was completed by the Engineering and Materials Division (FM) of the Infrastructure Laboratory (FL) of the U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Mr. Richard G. Lampo; Jonathan C. Trovillion was the associate investigator. Dr. Paul A. Howdyshell is Division Chief, CECER-FM and Dr. Michael J. O'Connor is Laboratory Chief, CECER-FL. Mr. Robert E. Muncy was the contractor to perform the falling ball and falling weight tests. Mr. Mark F. Williams of Kenney, Williams and Williams was the contractor to perform the Perfotest. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

COL Daniel Waldo, Jr., is Commander and Director of USACERL and Dr. L.R. Shaffer is Technical Director.

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EVALUATION OF TEST METHODS TO DETERMINE THE IMPACT RESISTANCE OF EXTERIOR INSULATION AND FINISH SYSTEMS (EIFS)

1 INTRODUCTION

Background

The use of exterior insulation and finish systems on Army facilities has increased substantially over the past 10 years, largely because they offer cost effectiveness, insulation efficiency, and a low-maintenance, aesthetically pleasing stucco-like finish. However, EIFS have not always performed as expected. Major failures and system deficiencies have been observed on Army facilities in recent years.[1] A leading cause of system failure or degradation is moisture infiltration into the system. Water can enter the system in many different ways, including cracks or punctures penetrating the outer lamina. Many of these cracks or punctures are caused by impacts to the system from various sources. For this reason, the impact resistance of EIFS is an extremely important property in maintaining long term system performance and appearance. It is also important to know the impact resistance of a given system relative to other systems so an architect/engineer can specify the correct system for a given use (fitness of purpose) at the lowest cost. Currently there are no industry-wide standard impact test methods used by all EIFS manufacturers. Most manufacturers state results from a given impact test method in their product literature; but since different test methods or variances of a given test method are used, these values cannot be compared throughout the industry. Also, many of these test methods were adapted from other materials tests and may not be applicable for use with EIFS.

Objective

The objective of this study was to evaluate test methods for impact resistance being used in industry and determine their validity for use with EIFS on Army facilities.

Approach

Researchers contacted selected EIFS manufacturers requesting systems for testing; 23 EIFS from 8 manufacturers were received. Three separate impact tests were performed on all 23 systems: a falling weight test, a falling ball test, and the European Perfotest. Based on the chemical and physical properties of the systems, researchers defined six assumptions about the relative impact resistance of polymer-based systems and one assumption about the impact resistance of polymer-modified systems. Researchers then compared the test results with the assumptions to draw conclusions and make recommendations.

[1] R.G. Lampo and J.C. Trovillion, *Exterior Insulation and Finish Systems (EIFS) on U.S. Army Facilities: Lessons Learned*, Technical Report M-91/02/ADA228572 (U.S. Army Construction Engineering Research Laboratory [USACERL], October 1990).

Mode of Technology Transfer

The results of this research were used to develop a draft standard test method presented to the ASTM Committee E-06.55, Performance of Building Constructions, Exterior Walls, in the fall of 1990 for possible adoption as a standard test method for determining the impact resistance of exterior insulation and finish systems (See Appendix A). Any test method adopted by ASTM should be incorporated into future updates of Corps of Engineers Guide Specification CEGS-07240.[2]

[2] CEGS-07240, *Exterior Insulation and Finish Systems* (Headquarters, U.S. Army Corps of Engineers [HQUSACE], December 1988).

2 EIFS CHARACTERISTICS

EIFS are nonload-bearing exterior wall cladding systems that can be used effectively in new construction or retrofit applications. These systems usually contain:

1. Molded expanded polystyrene insulation board (MEPS), commonly referred to as "bead board," or extruded expanded polystyrene insulation board (XEPS), commonly referred to as "blue board."

2. An adhesive or mechanical attachment of the insulation board to the substrate or both mechanical and adhesive attachments

3. A fabric-reinforced, or a fabric and chopped fiber-reinforced base coat

4. An acrylic stucco type or aggregate finish coat.

These systems are traditionally separated into the following two classes:

1. Polymer-based (PB) systems and
2. Polymer-modified (PM) systems.

Occasionally, the term "hard coat" is used to describe PM systems and "soft coat" to describe PB systems. However, these terms imply inaccuracies about the systems' mechanical properties, which are mainly dictated by the properties of the reinforced base coat. By virtue of the thick cementitious base coat, PM systems are hard. PB systems, on the other hand, vary in their properties depending on their base coat composition. For some PB systems, cement is added to the base coat mixture before application. These PB systems will be harder and more brittle than PB systems without cement. To avoid confusion, the industry discourages the use of the hard coat or soft coat terms.

The Exterior Insulation Manufacturers Association (EIMA), has established classifications for the different types of EIFS; they use "class PB" for the traditionally polymer-based EIFS and "class PM" for the traditionally polymer-modified EIFS. This report follows the current industry nomenclature.

Class PB Systems

The class PB systems are most commonly applied over MEPS insulation board that is adhesively attached, or adhesively and mechanically attached to the substrate.

The class PB system base coat may be a polymer-cement mix or all polymer-based (commonly referred to as synthetic). The thickness of the base coat varies depending on the number of layers applied and the type of reinforcing fabric used. The thickness of the base coat ranges from about 1/16 to 1/4 in.*
The reinforcement is typically a polymer-coated glass fiber mesh that is embedded into the base coat at the time of installation.

The finish coats for class PB systems are available in a wide variety of textures and colors.

* A metric conversion table is on page 50.

Class PM Systems

The class PM systems are most commonly applied over XEPS insulation board that is mechanically attached to the substrate.

The class PM system base coat is generally a polymer-modified cementitious mixture. The thickness of the base coat ranges from 1/4 to 3/8 in. The reinforcing fabric is generally a polymer-coated glass fiber mesh that is mechanically attached to the insulation board before the base coat is applied. This mesh serves not only to reinforce the base coat but also to aid in adhering the base coat to the insulation board. The base coat may also be additionally reinforced with chopped glass fibers.

As with the class PB systems, the finish coat in class PM systems is applied over the base coat and is available in a variety of colors, textures, or aggregate finishes.

System Assemblage

Although panelized systems (where factory-made EIFS panel sections are attached to the wall via mechanical tracks) are available, such systems are used less frequently because they cost more than on-site constructed systems. The majority of EIFS are constructed in the field directly on the building wall. The basic construction sequence is as follows:

1. Foam insulation boards of the appropriate thickness are attached to the substrate wall. For class PM systems, the boards are usually attached using mechanical fasteners. For class PB systems, the boards are typically attached adhesively, although mechanical fasteners or a combination of mechanical fasteners and adhesives may be used where desired or needed.

2. After appropriate adhesive curing, the system base coat is applied over the attached insulation boards. For class PB systems, the specified reinforcing mesh is then worked into the wet base coat. For class PM systems, the reinforcing mesh is mechanically attached in the same operation as attaching the insulation boards. If more than one layer of mesh is specified, the procedure is repeated after allowing the previous layer to cure.

3. When the base coat layer has appropriately cured, the system finish coat is applied.

System Advantages

One advantage of EIFS is that they offer very good insulating properties. Because these systems are applied to the exterior of a building, they eliminate thermal bridging to the outside caused by floors or ceilings. They also greatly decrease the thermal shock, or temperature range, that the structural load-bearing wall experiences, which helps to prolong the lifetime and reduce maintenance to the wall.

Another advantage of EIFS is that they can be cost efficient; depending on geographic location, local energy costs, building design, HVAC system type, etc, an EIFS installation can pay for itself over time. Life cycle costs are low because the systems require little maintenance, such as periodic painting. Also, since they are applied to the exterior of a building, normal operations within the building need not be stopped or altered during the system installation. EIFS can also improve the appearance of buildings. The wide range of finish coats available gives the designer/architect ample freedom in choosing colors and designs to enhance the building architecture.

EIFS are easily applied and can be installed in a relatively short time. They can also be installed over a wide range of substrates, which greatly increases their versatility.

Considerations for System Use

All components of EIFS function together to provide insulation, weather/moisture protection, durability, and an aesthetically pleasing appearance. EIFS are designed to be a moisture barrier; however, if water enters the system, its integrity can be affected. Therefore, deficiencies that allow water to penetrate the system are of major concern. For this reason, the impact resistance of EIFS is a very important property to ensure overall system integrity and performance.

EIFS were introduced into the U.S. market about 15 years ago, and therefore represent a relatively new technology. Industry-wide standard specifications and test methods have not been fully developed and/or uniformly adopted. The impact resistance of these systems varies widely according to the types and number of layers of reinforcing fabric, the composition and thickness of the base coat, differences between the formulations of different manufacturers, and the application methods used. The information in this report was obtained to increase the knowledge of how EIFS respond to impact loadings. The intent of gathering this information was to speed up the process of developing a standard impact test method to be used throughout the EIFS industry. With this information, selection criteria could be developed that would allow better decisions to be made when specifying EIFS in retrofit or new construction applications.

3 TEST PROGRAM

Specimen Preparation

Twenty-three different systems from 8 manufacturers were tested; 17 were polymer-based (class PB) and 6 were polymer-modified (class PM) systems. To protect proprietary information, each system was identified only by an alphanumeric code composed of a letter to designate the manufacturer, a number to designate a given system, and PB or PM to designate the system class. Table 1 lists the codes and generic information about the class PB systems. Table 2 lists the codes and generic information about the class PM systems.

The EIFS were applied over 4 ft by 8 ft frames made from standard 2 in. by 4 in. lumber with a 16 in. center-to-center stud spacing parallel to the 4 ft dimension. The fasteners used for the lumber were sixteenpenny nails. A 4 ft by 8 ft by 1/2 in. sheet of gypsum sheathing board was attached using 1-5/8 in. drywall screws (Figure 1). The EIFS were applied over the gypsum sheathing by representatives from each manufacturer according to individual installation procedures. Four 4 ft by 8 ft panels of each system were required for the tests. After applying the EIFS, the panels were allowed to cure for at least 28 days before testing.

Tests Performed

Three tests were performed on samples of each of the 23 systems: a falling weight test, a falling ball test, and the European Perfotest. The first two tests were selected for evaluation because they are the tests most commonly used by industry; the Perfotest was selected because it can be used in the field as a quality assurance tool.

Because EIFS represent a relatively new construction technology, specifications and test methods for these systems have not been fully developed. When it became apparent that the impact resistance of these systems was a concern, most manufacturers adopted industry accepted impact test methods developed for other materials. These tests had to be modified for EIFS to accommodate the material differences. Because these modifications were manufacturer specific, comparisons based on impact resistance between manufacturers were virtually impossible. Another problem was that a wide variety of tests were used by the many EIFS manufacturers. Through all this confusion, two tests became used in some way by most of the manufacturers: a falling weight (indentation) test and a falling ball test.

The falling weight test used most by EIFS manufacturers incorporates an apparatus developed by the Gardner Laboratory (Silver Spring, MD) and is commonly referred to as the "Gardner Test." In this test, a cylindrical weight falls through a guide tube and strikes a 1/2-in. hemispherical indenter resting on the specimen. This apparatus is used in ASTM test method D2794,[3] which was developed to test the impact resistance of organic coatings such as paint. D2794 is specified by several manufacturers. This apparatus is also specified by the Exterior Insulation Manufacturers Association, EIMA.[4] However, this

[3] ASTM D2794-90, "Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)," *Annual Book of ASTM Standards*, Vol 06.01 (American Society for Testing and Materials [ASTM], 1991), pp 404-405.

[4] EIMA Test Method & Standard 101.86, *Standard Test Method for Resistance of Exterior Insulation Finish Systems to the Effects of Rapid Deformation (Impact)*, EIMA Guideline Specification for Exterior Insulation and Finish Systems-Class PB Type A, Appendix A, April 1987.

Table 1

Information on the Polymer-Based Systems

System ID	System Description	Average Base Coat Thickness (mm)	(in.)
A1-PB	A single layer of standard reinforcing fabric with a cementitious base coat.	1.35	0.0531
A2-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a cementitious base coat.	3.01	0.118
B2-PB	a single layer of standard reinforcing fabric with a cementitious base coat.	1.32	0.0520
B3-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a cementitious base coat.	3.14	0.124
E1-PB	A single layer of standard reinforcing fabric with a cementitious base coat.	2.02	0.0795
E2-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a cementitious base coat.	3.51	0.138
E3-PB	Two layers of standard reinforcing fabric with a cementitious base coat.	2.63	0.103
E4-PB	A single layer of standard reinforcing fabric with a synthetic base coat.	1.69	0.0666
F1-PB	A single layer of standard reinforcing fabric with a cementitious base coat.	1.30	0.0512
F2-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a cementitious base coat.	3.54	0.139
G1-PB	A single layer of standard reinforcing fabric with a cementitious base coat.	1.87	0.0736
G2-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a cementitious base coat.	2.71	0.107
G3-PB	Two layers of high impact reinforcing fabric with a cementitious base coat.	4.34	0.171
H1-PB	A single layer of standard reinforcing fabric with a cementitious base coat.	0.95	0.0374
H2-PB	A single layer of standard reinforcing fabric with a synthetic base coat.	2.10	0.0827
H3-PB	A layer of standard reinforcing fabric and a layer of high impact fabric in a synthetic base coat.	2.53	0.0996
H4-PB	Two layers of standard reinforcing fabric with a synthetic base coat.	2.79	0.110

Table 2

Information on the Polymer-Modified Systems

System ID	System Description	Average Base Coat Thickness (mm)	(in.)
A3-PM	A standard PM system.	9.82	0.387
B1-PM	A standard PM system.	5.31	0.209
C1-PM	A PM system using a wire mesh instead of a glass fiber mesh.	11.18	0.440
D1-PM	A standard PM system.	8.80	0.346
D2-PM	The base coat is thicker on this system relative to the standard system.	9.71	0.382
F3-PM	A standard PM system.	5.94	0.234

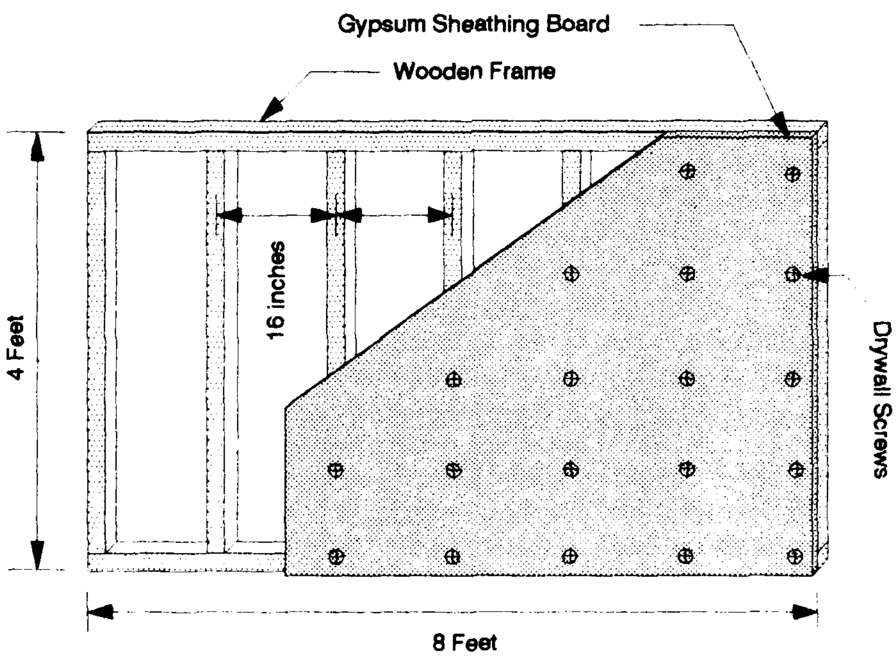


Figure 1. Test Frame for EIFS Application.

test has not been universally accepted by EIFS manufacturers and is not specific enough to eliminate variability between manufacturers conducting the test.

A falling ball test has been specified and conducted by a large percentage of manufacturers. In this test, a steel ball of some given size and weight is allowed to fall onto the specimen from a given height. This can be accomplished by either a vertical drop or by using a pendulum. The problem is that the weight and diameter of the ball and the mechanism for attaching the specimen are seldom the same between manufacturers, even when they cite the same test method. The falling ball test most commonly specified by EIFS manufacturers is ASTM test method D1037.[5] This method contains several tests developed to evaluate the properties of particle board. In the falling ball test, the ball would have to drop over 50 ft to cause failure in some systems. This is not feasible for most testing facilities, especially when trying to hit an 8-in. by 8-in. sample as specified in the test method. To overcome this, the most common modification to this method is to increase the size and weight of the ball. This makes comparison between manufacturers meaningless even when the same test is specified. Other variables encountered include sample size, sample preparation, and attachment to the test fixture base.

Since the goal of the current research was to determine whether the commonly used tests were applicable to EIFS, researchers also modified the two tests to fit testing needs and capabilities. This was perceived as a first step in the process of developing a specific industry standard test method that would be used by all EIFS manufacturers.

A standard test widely used in Europe is the Perfotest.[6] Unlike the falling weight and falling ball tests, which incorporate a constant indentor size and a variable force, the Perfotest uses a constant force and variable indenter size. This device is hand held and can be used in the laboratory or in the field as a quality assurance tool.

Data Reduction

For both the falling weight test and the falling ball test, a mean-failure-energy was determined using methods outlined in ASTM D3029.[7] The first step in calculating a mean-failure-energy is to calculate a mean-failure-height. The mean-failure-height is calculated using the following formula:

$$h = h_o + d_h(A/N \pm 0.5) \qquad \text{[Eq 1]}$$

where:

h	=	the mean-failure-height,
h_o	=	the lowest height at which an event occurred,
d_h	=	the increment in drop height,
N	=	the total number of failures or nonfailures, whichever is smaller (whatever is used, either failures or nonfailures, is called an event), and
A	=	is given by the expression,

[5] ASTM D1037-89, "Standard Test Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials," *Annual Book of ASTM Standards*, Vol 04.09 (ASTM, 1991), pp 169-198.

[6] European Union for Technical Agreement in Construction, *UEAtc Directives for the Assessment of External Insulation Systems for Walls (Expanded Polystyrene Insulation Faced with a Thin Rendering)*, M.O.A.T, n 22, June 1988.

[7] ASTM D3029-90, "Standard Test Methods for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Tup (Falling Weight)," *Annual Book of ASTM Standards*, Vol 08.02 (ASTM, 1991), pp 517-528.

$$A=\sum_{i=0}^{k} in_i, \qquad \text{[Eq 2]}$$

where: i = 0,1,2....k (a counting index starting at h_o),
n_i = the number of events that occurred at h_i, and h_i is given by the expression,

$$h_i = h_o + id_h \qquad \text{[Eq 3]}$$

In calculating the mean-failure-height, the negative sign is used when the events are failures and the positive sign is used when the events are nonfailures.

The estimated standard deviation of the sample is calculated using the following formula,

$$S_h = 1.62d_h[B/N-(A/N)^2] + 0.047d_h \qquad \text{[Eq 4]}$$

where: B is given by the expression,

$$B=\sum_{i=0}^{k} i^2 n_i \qquad \text{[Eq 5]}$$

This formula is valid only if $[B/N-(A/N)^2] > 0.3$.

The estimated standard deviation of the sample mean-failure-height is given by:

$$S_{hbar} = G*S_h/\sqrt{N} \qquad \text{[Eq 6]}$$

where: S_{hbar} = the estimated standard deviation of the mean-failure-height,
G = a function of S_h/d_h.[8]

The mean-failure-energy, MFE, can be calculated using the following formula:

$$MFE = h * w \qquad \text{[Eq 7]}$$

[8] Weaver, O.R., "Using Attributes to Measure a Continuous Variable in Impact Testing Plastic Bottles," *Materials Research and Standards*, Vol 6, No. 6 (June 1966), pp 285-291.

where: h = the mean-failure-height,
w = the constant drop weight used in testing.

The estimated standard deviation of the MFE is given:

$$S_{MFE} = S_{hbar} * w \qquad \text{[Eq 8]}$$

Sample calculations using these formulas are given in Appendix B.

Falling Weight Test

Apparatus

In the falling weight test, the apparatus consists of a vertical tube with a slot cut down the side. The slot in the side of the tube allows the tester to control the drop height of the weight by using a prong attached to the weight that protruded through the slot. A 2- or 4-lb cylindrical weight was dropped through the tube onto a 1/2-in. hemispherical indenter, which rested on the specimen (Figure 2). The

Figure 2. Test Apparatus for the Falling Weight Test.

vertical tube was marked off in inches and had a maximum drop height of 60 in. For this testing, a Gardner-SPI modified, variable height impact tester was used.[9]

Test Specimens

Because the full-size test panels were not well adapted to this test, smaller specimens were cut from the full size test panels using a 10-in. circular saw and a diamond masonry blade. This yielded six 14-in. by 46-in. specimens from each test panel. These six specimens were adequate to conduct this test.

Test Procedure

For this test, the "up-and-down" method was used.[10] An initial drop height was chosen which was presumed to be less than what was necessary to cause failure. The specimen was then impacted from this drop height. If no failure occurred, the drop height was increased by a given increment, and the specimen was impacted again at a new location. This pattern was repeated until a failure occurred. When a failure occurred, the drop height was decreased by the same increment and the specimen was impacted again. This procedure was repeated until the specimen had no more area available for a new impact.

This test was conducted on all 23 EIFS using both a 2-lb and 4-lb weight. (The EIMA test method uses a 4-lb weight.[11]) The up-and-down increment in drop height was 1-in. Impact points were at least 4-in. from the edges of the specimen and at least 4-in. apart. No area on the specimen was impacted more than once. A failure was defined as any crack visible to the naked eye under ordinary light. All light readings were made with a Gossen Luna-Pro Light meter. For the falling weight test, the reading was scale #13, which is equal to 700 Lux_{ca}. These lighting conditions allowed the detection of cracks. This criterion was based on the assumption that a crack visible to the naked eye would be more than sufficient to allow moisture to penetrate the system.

Results

The data from the 2-lb Gardner test on class PB systems are given in Table 3. Significant values used to calculate the mean-failure-energy, MFE, and the standard deviation of MFE, S_{MFE}, also are presented in Table 3. MFE and S_{MFE} are plotted in a bar chart in Figure 3. The shaded section on the top of the bars is the standard deviation and the line in the center of this region is the mean-failure-energy. No standard deviation is shown for system E4-PB because the distribution of the data was non-Gaussian and therefore the formulas for the standard deviation were not valid.

The data from the 2-lb Gardner test on class PM systems are given in Table 4. MFE and S_{MFE} are plotted in Figure 4. No standard deviations are shown for four systems because they did not fail at the upper limits of the test.

The data from the 4-lb Gardner test on class PB systems are given in Table 5 and plotted in Figure 5. No values are shown for system H1-PB because this system failed at the lower limits of testing.

The data from the 4-lb Gardner test on class PM systems are given in Table 6 and plotted in Figure 6. No standard deviations are shown for systems B1-PM and C1-PM because the distribution of the data was non-Gaussian.

[9] Suitable instruments are the Gardner-SPI Modified Impact Tester, available from BYK-Gardner, Inc., Gardner Laboratory, 2435 Linden Lane, Silver Spring, MD 20910, or the Universal Impact Tester Model No. 172, available from Paul N. Gardner Co., Inc., 316 N.E. First St., PO Box 10688, Pompano Beach, FL 33061-6688. Equivalent apparatus may be used.

[10] ASTM D3029-90.

[11] EIMA 101.86.

Table 3

Results of 2-lb Gardner Test on PB Systems

System ID	h (in.)	S_h (in.)	G	S_{hbar} (in.)	MFE (in.-lb)	S_{MFE} (in.-lb)
A1-PB	15.50	4.44	0.91	1.08	31.00	2.16
A2-PB	49.70	3.11	0.92	0.74	99.40	1.48
B2-PB	5.04	1.96	0.93	0.47	10.08	0.95
B3-PB	9.57	1.01	0.99	0.25	19.14	0.52
E1-PB	8.90	0.87	1.01	0.23	17.80	0.46
E2-PB	12.13	1.44	0.95	0.34	24.26	0.69
E3-PB	10.97	3.26	0.92	0.77	21.94	1.55
E4-PB	17.96	29.36	Non-Gaussian		35.92	---------
F1-PB	11.34	6.54	0.90	1.05	22.68	2.11
F2-PB	26.73	9.31	0.89	1.62	53.46	3.25
G1-PB	7.56	2.17	0.93	0.35	15.12	0.71
G2-PB	8.50	1.90	0.93	0.47	17.00	0.95
G3-PB	14.44	7.49	0.89	1.73	28.88	3.46
H1-PB	2.98	0.93	1.00	0.18	5.96	0.36
H2-PB	7.47	1.08	0.98	0.18	14.94	0.37
H3-PB	51.38	2.05	0.93	0.47	102.76	0.95
H4-PB	17.77	2.31	0.93	0.55	35.54	1.11

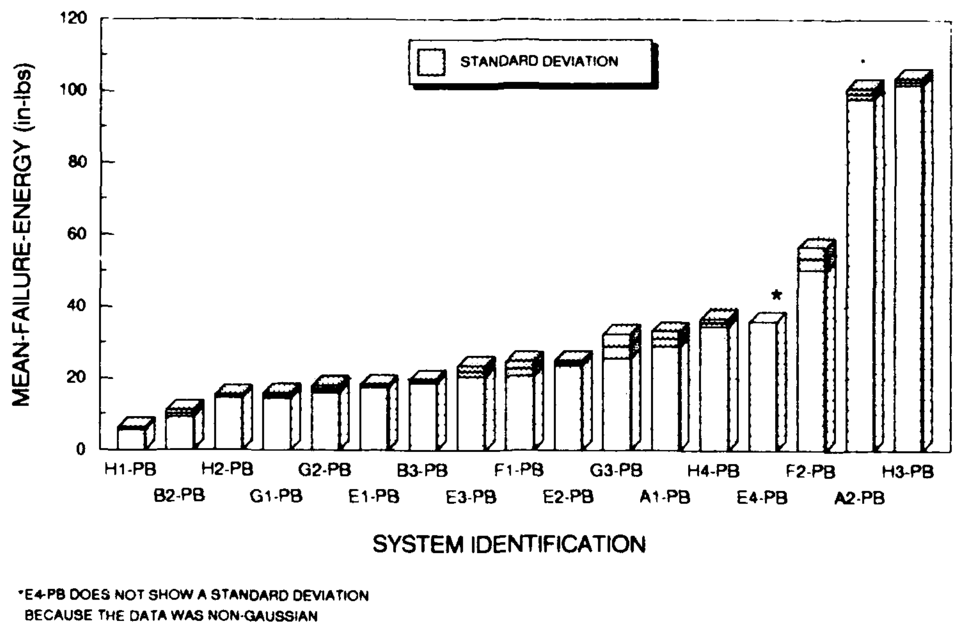


Figure 3. MFEs for 2-lb Gardner Test on Class PB EIFS.

Table 4

Results of 2-lb Gardner Test on PM Systems

System ID	h (in.)	S_h (in.)	G	S_{hbar} (in.)	MFE (in.-lb)	S_{MFE} (in.-lb)
A3-PM	60	Did Not Fail at Limits of Test			120	-----
B1-PM	57.64	1.87	0.94	0.46	115.28	0.94
C1-PM	60	Did Not Fail at Limits of Test			120	-----
D1-PM	60	Did Not Fail at Limits of Test			120	-----
D2-PM	60	Did Not Fail at Limits of Test			120	-----
F3-PM	35.38	10.18	0.88	1.75	70.76	3.51

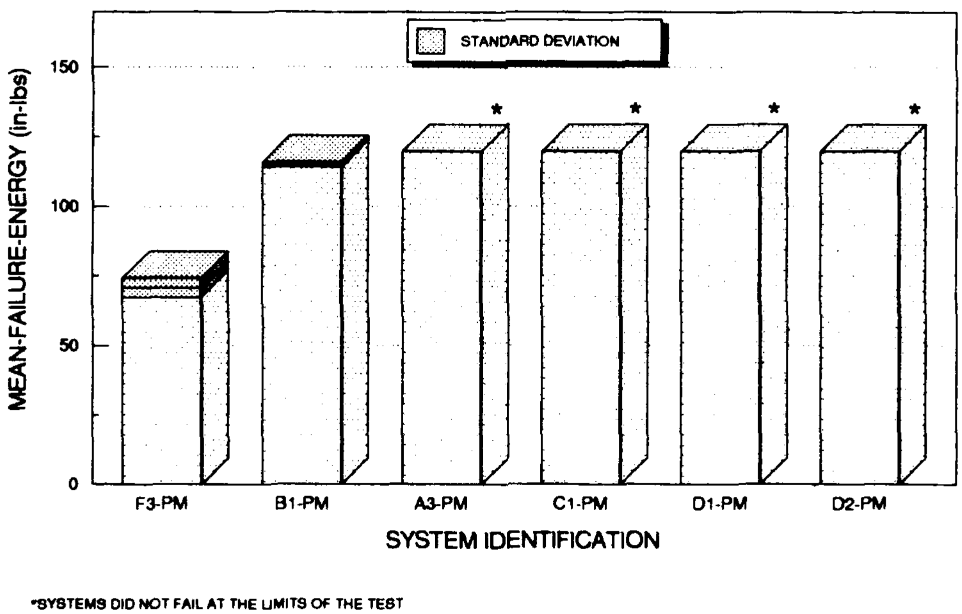


Figure 4. MFEs for 2-lb Gardner Test on Class PM EIFS.

Table 5

Results of 4-lb Gardner Test on PB Systems

System ID	h (in.)	S_h (in.)	G	S_{hbar} (in.)	MFE (in.-lb)	S_{MFE} (in.-lb)
A1-PB	7.06	1.46	0.95	0.24	28.24	0.98
A2-PB	25.86	12.02	0.87	1.88	103.44	7.56
B2-PB	2.16	0.72	1.05	0.13	8.64	0.53
B3-PB	6.34	0.27	1.25	0.06	25.36	0.25
E1-PB	3.67	0.72	1.05	0.13	14.68	0.54
E2-PB	5.97	2.72	0.92	0.45	23.88	1.84
E3-PB	7.69	3.13	0.92	0.50	30.76	2.03
E4-PB	5.53	1.17	0.97	0.19	22.12	0.80
F1-PB	6.29	1.01	0.99	0.26	25.16	1.07
F2-PB	14.24	2.09	0.93	0.50	56.96	2.01
G1-PB	3.70	1.17	0.97	0.29	14.80	1.18
G2-PB	5.00	2.07	0.93	0.34	20.00	1.36
G3-PB	6.95	2.33	0.92	0.38	27.80	1.55
H1-PB	0.00	Did Not Pass at Lower Limits of Test			0.00	------
H2-PB	3.70	2.25	0.92	0.53	14.80	2.15
H3-PB	27.67	9.55	0.89	1.57	110.68	6.31
H4-PB	8.05	2.91	0.92	0.49	32.20	1.99

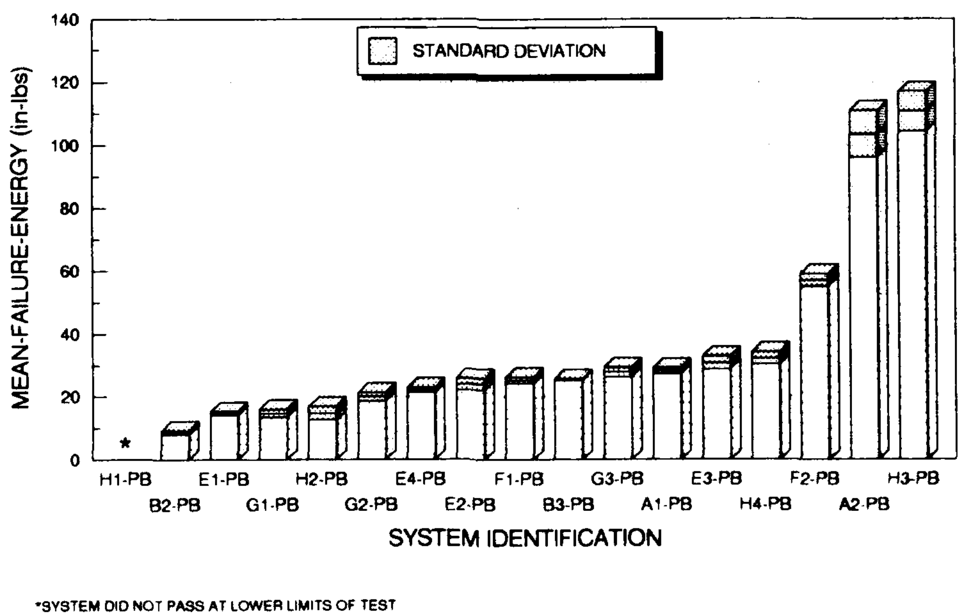


Figure 5. MFEs for 4-lb Gardner Test on Class PB EIFS.

Table 6

Results of 4-lb Gardner Test on PM Systems

System ID	h (in.)	S_h (in.)	G	S_{hbar} (in.)	MFE (in.-lb)	S_{MFE} (in.-lb)
A3-PM	32.39	10.73	0.88	1.78	129.56	7.14
B1-PM	25.95	38.27	Non-Gaussian		103.80	-----
C1-PM	43.82	18.67	Non-Gaussian		175.28	-----
D1-PM	36.24	6.24	0.90	1.08	144.96	4.35
D2-PM	46.93	5.88	0.90	1.00	187.72	4.02
F3-PM	16.11	8.16	0.89	2.02	64.44	8.10

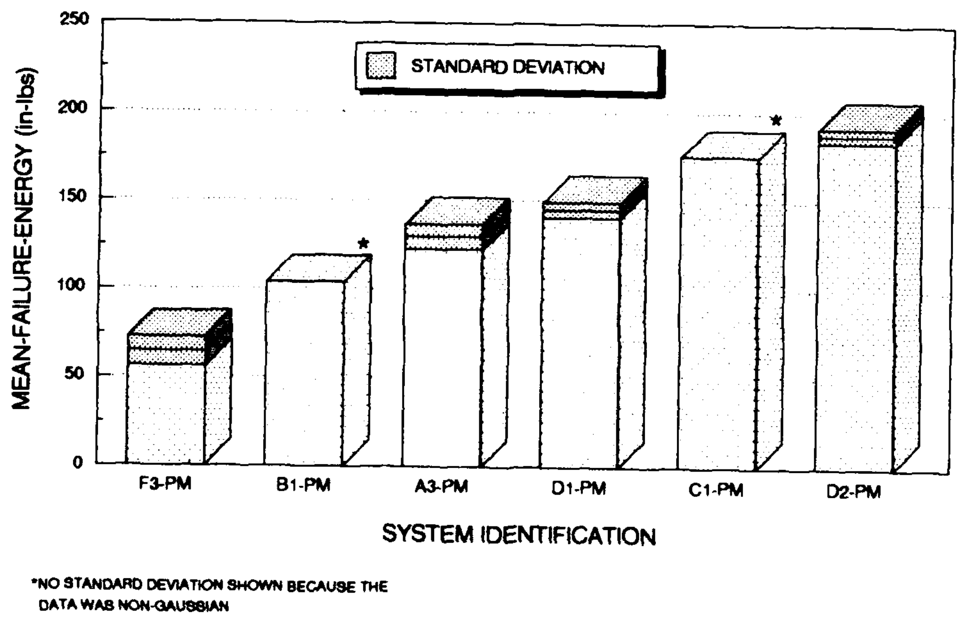


Figure 6. MFEs for 4-lb Gardner Test on Class PM EIFS.

Falling Ball Test

Apparatus

For the falling ball test, researchers use a 2-lb steel ball with a 2-3/8 in. diameter. This ball was suspended by a 30-ft length of 0.025-in. diameter Kevlar[R] cord. The maximum drop height for the test was 15 ft.[12] If a system could withstand impacts from the 2-lb ball without failing, a 4-lb steel ball with a 3-in. diameter was used in the test. (Time and funding considerations did not permit the retesting of the other specimens with the 4-lb ball as would be necessary to establish the correlation of the results with those from the 2-lb ball.) The ball was allowed to swing in pendular fashion and the drop height was measured vertically from the bottom of the swing (Figure 7). A pendulum design made controlling the rebound of the ball easier than if a straight vertical drop was used.

A support for the test panel was constructed from vertical steel columns with horizontal supports. Figures 8 and 9, respectively, show the front and back of the support). A 20-ft long 2-by 4-in. board marked off in 3-in. increments was constructed to measure the drop height of the ball.

Test Specimens

A single full-size test panel was adequate for conducting this test. The test panel was supported vertically against the horizontal supports of the steel columns. The test panel was rigidly fixed to these horizontal supports by 3-in. lag screws. The lag screws were driven through the horizontal supports into the studs of the test frame.

Test Procedure

For this test, the up-and-down procedure also was used. The increment between drop heights was 3 in. Impact points were at least 6 in. from the edges of the test panel and 6 in. apart. For reference, a grid of 6-in. squares was marked on the surface of the test panel using a chalk line. A failure was defined as any crack visible to the naked eye under ordinary light. All light readings were made with a Gossen Luna-Pro Light meter. For the falling ball test, which was conducted in a crane bay, the reading was scale #10 or 88 Lux_{ca}. This was adequate for most panels, but for one set with a dark green finish coat, a Smith Victor Model 880 reflector with a #2 Super Flood (EBV) was used to enhance the lighting. This increased the lighting on the test panel to scale #11 or 175 Lux_{ca}.

Results

The data from the 2-lb falling ball test on class PB systems are given in Table 7 and plotted in Figure 10. No values are shown for system H1-PB because this system failed at the lower limits of testing. No standard deviations are shown for systems A2-PB, B3-PB, G3-PB, and H3-PB because they did not fail at the upper limits of testing.

The data from the 2-lb falling ball test on class PM systems are given in Table 8 and plotted in Figure 11. No standard deviations are shown for systems A3-PM, D1-PM, and D2-PM because the distribution in the data was non-Gaussian.

[12] A. Smith, R.E. Muncy, and S.C. Sweeney, *Criteria for Evaluating Impact Damage Resistance of Exterior Insulation and Finish Systems*, Technical Report M-335/ADB079523 (U.S. Army Construction Engineering Research Laboratory [USACERL], November 1983).

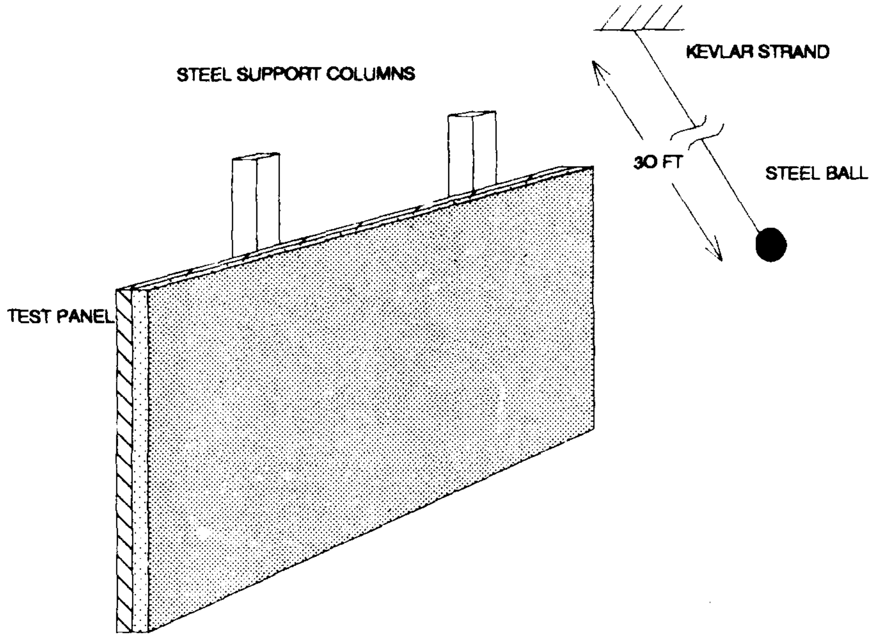


Figure 7. Diagram of the Falling Ball Apparatus.

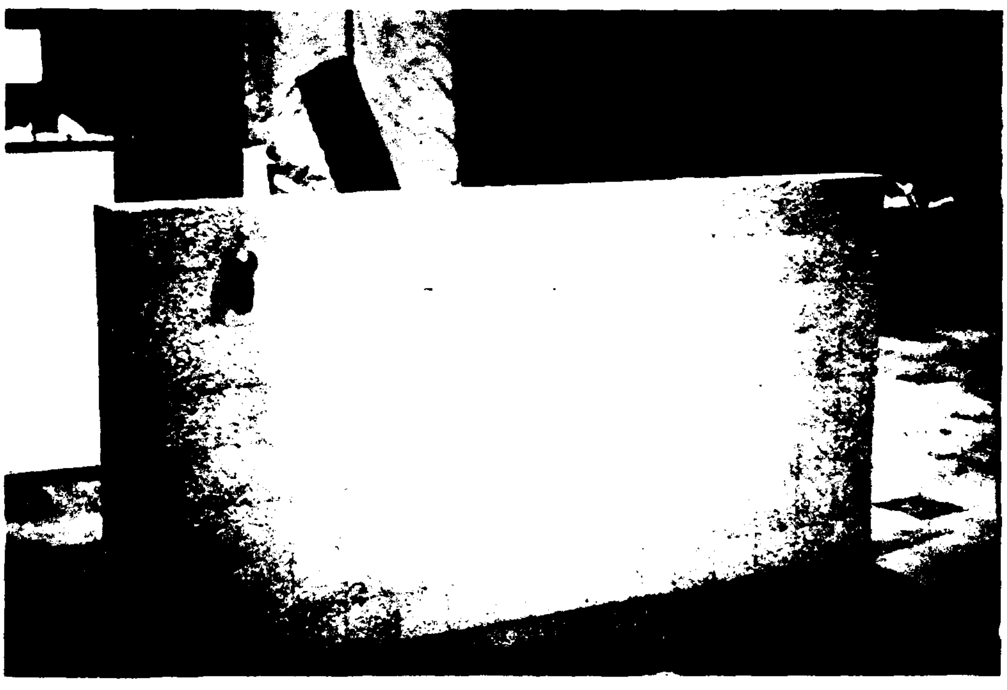


Figure 8. Front View of the Support for the Falling Ball Test.

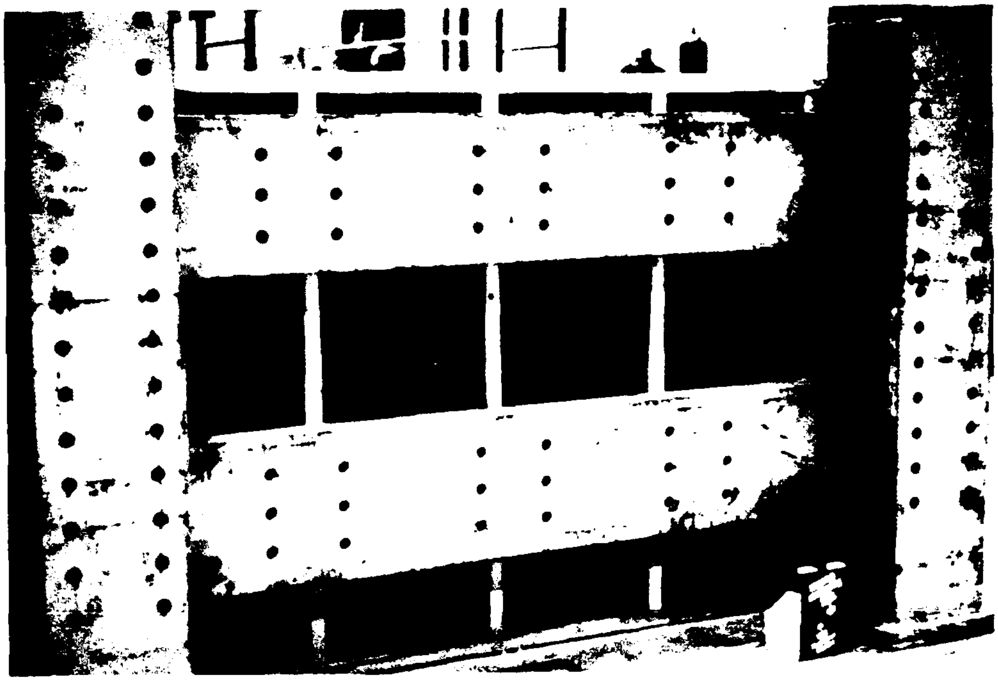


Figure 9. Back View of the Support for the Falling Ball Test.

Table 7

Results of 2-lb Falling Ball Test on PB Systems

System ID	h (in.)	S_h (in.)	G	S_{hbar} (in.)	MFE (ft-lb)	S_{MFE} (ft-lb)
A1-PB	2.93	0.54	0.93	0.10	5.86	0.21
A2-PB	15.00	Did Not Fail at Limit of Test			30.00	-----
B2-PB	0.84	0.44	0.94	0.07	1.68	0.16
B3-PB	15.00	Did Not Fail at Limit of Test			30.00	-----
E1-PB	0.86	0.19	1.04	0.03	1.72	0.08
E2-PB	6.99	0.62	0.92	0.11	13.98	0.23
E3-PB	8.61	2.30	0.89	0.54	17.22	1.09
E4-PB	5.14	2.94	0.87	0.62	10.28	1.25
F1-PB	3.22	0.75	0.92	0.15	6.44	0.31
F2-PB	14.46	1.20	0.91	0.24	28.92	0.53
G1-PB	2.50	0.99	0.91	0.18	5.00	0.36
G2-PB	6.77	1.41	0.90	0.26	13.54	0.53
G3-PB	15.00	Did Not Fail at Limit of Test			30.00	-----
H1-PB	0.00	Did Not Pass at Limit of Test			0.00	-----
H2-PB	1.09	0.25	0.99	0.04	2.18	0.10
H3-PB	15.00	Did Not Fail at Limit of Test			30.00	-----
H4-PB	2.92	0.82	0.92	0.14	5.84	0.30

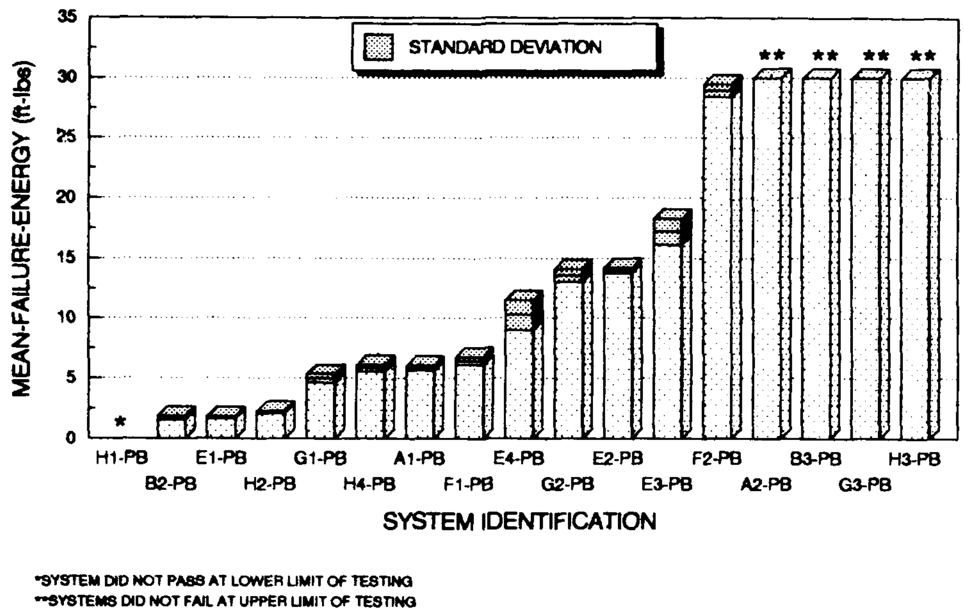


Figure 10. MFEs for 2-lb Falling Ball Test on Class PB EIFS.

Table 8

Results of 2-lb Falling Ball Test on PM Systems

System ID	h (ft)	S_h (ft)	G	S_{hbar} (ft)	MFE (ft-lb)	S_{MFE} (ft-lb)
A3-PM	4.41	4.37	Non-Gaussian		8.82	-----
B1-PM	3.8	2.76	0.88	0.52	7.60	1.06
C1-PM	5.49	1.02	0.91	0.18	10.98	0.37
D1-PM	5.68	50.30	Non-Gaussian		11.36	------
D2-PM	10.33	7.09	Non-Gaussian		20.66	------
F3-PM	3.58	2.72	0.88	0.72	7.16	1.45

The data from the 4-lb falling ball test on class PB systems are given in Table 9 and plotted in Figure 12. Only systems that did not fail in the 2-lb falling ball test were tested with the 4-lb ball. No standard deviations are shown for A2-PB and G3-PB because the distribution in the data was non-Gaussian. H3-PB did not fail at the upper limits of the test.

No class PM systems were tested in the 4-lb falling ball test.

European Perfotest

Apparatus

Perfotest is a hand-held field test apparatus developed as an indentation test for European EIFS. It is calibrated with a hemispherical indentor to reproduce the impact of a steel ball with a mass of 0.500 kg falling from a height of 0.765 m. This is a constant-force device that has 9 interchangeable cylindrical indenting heads (Figure 13).[13] The indenting head sizes are: 4, 6, 8, 10, 12, 15, 20, 25, and 30 mm.

Test Specimens

A single full-size test panel was adequate for this test method. To provide a rigid support, this test panel was supported in the same manner that the test panels were supported in the falling ball test.

Test Procedure

In this test, groups of five indentations were conducted. Each group of five was made with the same indenting head. If two or fewer failures were recorded, the next group of five indentations was made with

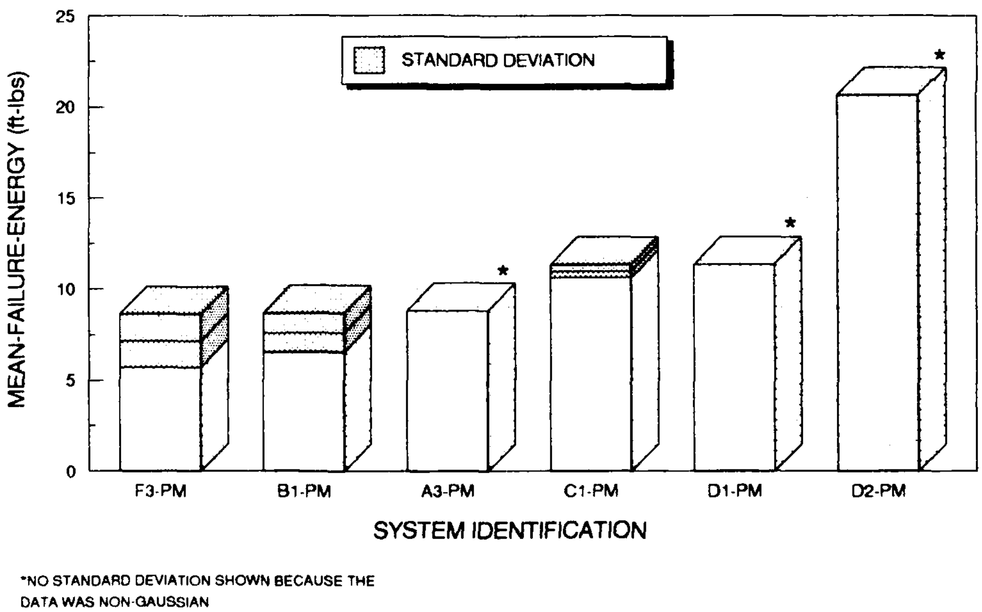


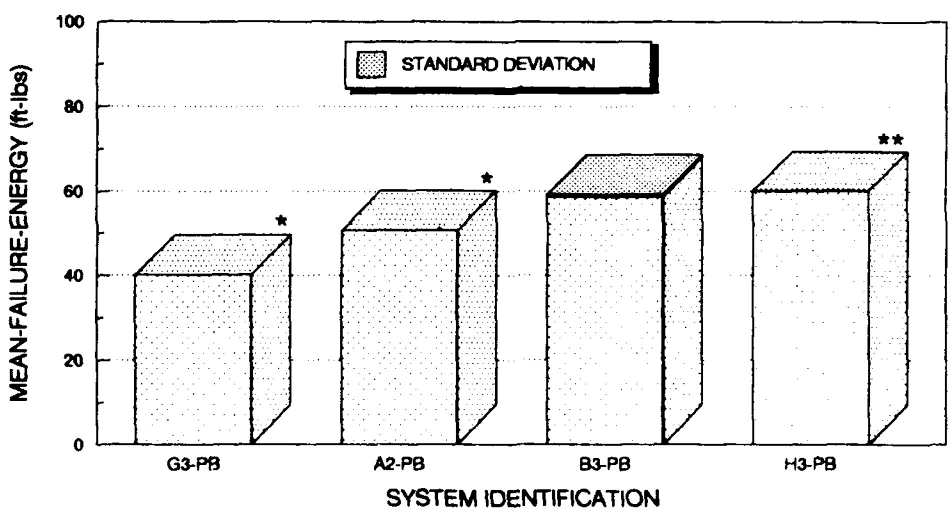
Figure 11. MFEs for 2-lb Falling Ball Test on Class PM EIFS.

[13] European Union for Technical Agreement in Construction.

Table 9

Results of 4-lb Falling Ball Test on PB Systems

System ID	h (ft)	S_h (ft)	G	S_{hbar} (ft)	MFE (ft-lb)	S_{MFE} (ft-lb)
A2-PB	12.68	4.30	Non-Gaussian		50.72	-----
B3-PB	14.72	0.32	0.96	0.07	58.88	0.28
G3-PB	10.06	4.81	Non-Gaussian		40.24	-----
H3-PB	15.00	Did Not Fail at Limits of Test			60.00	-----



*STANDARD DEVIATIONS ARE NOT SHOWN BECAUSE THE DATA IS NON-GAUSSIAN
**SYSTEM DID NOT FAIL AT UPPER LIMITS OF TESTING

Figure 12. MFEs for 4-lb Falling Ball Test on Class PB EIFS.

Figure 13. The Perfotest Apparatus.

the next smaller head size. If three or more failures were recorded in a group of five indentations, the next five indentations were made with the same sized head. This was repeated until three groups of five indentations produced at least three out of five failures. The system was then rated as the smallest sized head that did not cause three or more failures in three groups of five indentations. For example, if a system had at least three failures in three groups of five indentations with the 10 mm head, it would be rated as being able to withstand an indentation from the 12 mm head.

This test procedure was conducted using two different failure criteria. The first, called the standard failure criterion, defined a failure to be any indentation that caused a perforation in the surface visible to the naked eye under ordinary light. This included cracks formed in the area surrounding the impact. The second, called the refusal failure criterion, defined a failure to be a perforation in the surface such that the entire indenting head penetrates into the system until the chuck holding the indenting head rests on the surface.

Results

Table 10 gives the results from the Perfotest on class PB EIFS and Table 11 gives the results for class PM EIFS. Both the standard failure criterion and the refusal failure criterion data are presented in these tables. These tables also include a value that gives the energy per unit area for each test. This value was derived by dividing the energy of the Perfotest apparatus (3.75 J) by the surface area of the indenting head the system was rated at in the test. This value gives the energy per unit area the system was able to absorb without failing. Figure 14 graphically presents a comparison of the standard and refusal criteria for all 23 EIFS tested. No values are shown for system D2-PM because this system did not fail at the upper limits of testing. No values are shown for system H1-PB because it failed at the lower limits of testing. Figures 15 and 16 show the results for the standard Perfotest on class PB and class PM systems, respectively. Figures 17 and 18 show the results for the refusal Perfotest on class PB and class PM systems, respectively.

Table 10

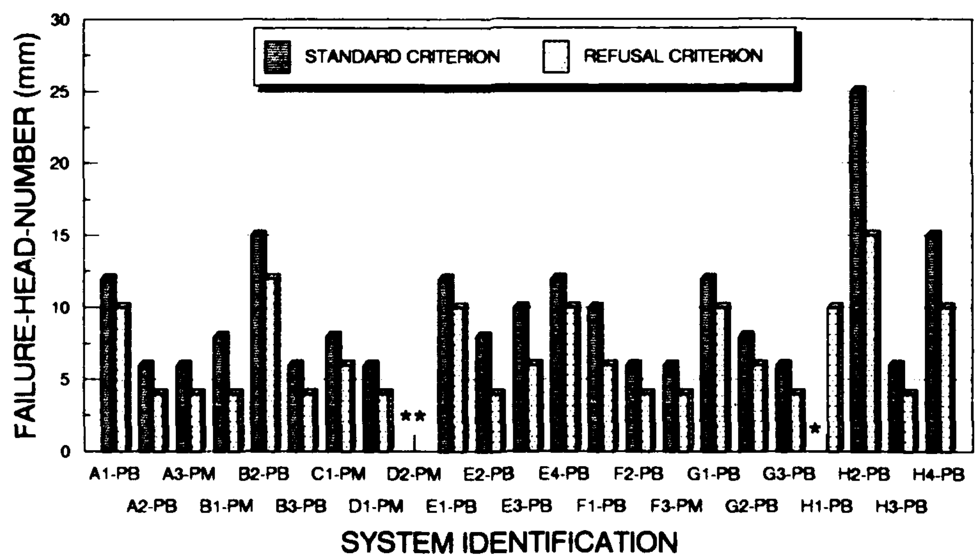
Perfotest Data for Both Standard and Refusal Failure Criteria on PB Systems

System ID	Standard Criterion		Refusal Criterion	
	Head Number (mm)	(kJ/M^2)	Head Number (mm)	(kJ/M^2)
A1-PB	12	16	10	23
A2-PB	6	66	4	150
B2-PB	15	11	12	16
B3-PB	6	66	4	150
E1-PB	12	16	10	23
E2-PB	8	37	4	150
E3-PB	10	23	6	66
E4-PB	12	16	10	23
F1-PB	10	23	6	66
F2-PB	6	66	4	150
G1-PB	12	16	10	23
G2-PB	8	37	6	66
G3-PB	6	66	4	150
H1-PB	No Passes	---	10	23
H2-PB	25	3.8	15	11
H3-PB	6	66	4	150
H4-PB	15	11	10	23

Table 11

Perfotest Data for Both Standard and Refusal Failure Criteria on PM Systems

System ID	Standard Criterion Head Number (mm)	Standard Criterion (kJ/M^2)	Refusal Criterion Head Number (mm)	Refusal Criterion (kJ/M^2)
A3-PM	6	66	4	150
B1-PM	8	37	4	150
C1-PM	8	37	6	66
D1-PM	6	66	4	150
D2-PM	No Failures	---	No Failures	---
F3-PM	6	66	4	150



*SYSTEM DID NOT PASS AT LOWER LIMITS OF TESTING
**SYSTEM DID NOT FAIL AT UPPER LIMITS OF TESTING

Figure 14. Failure-Head-Numbers for the European Perfotest on Class PB and Class PM EIFS.

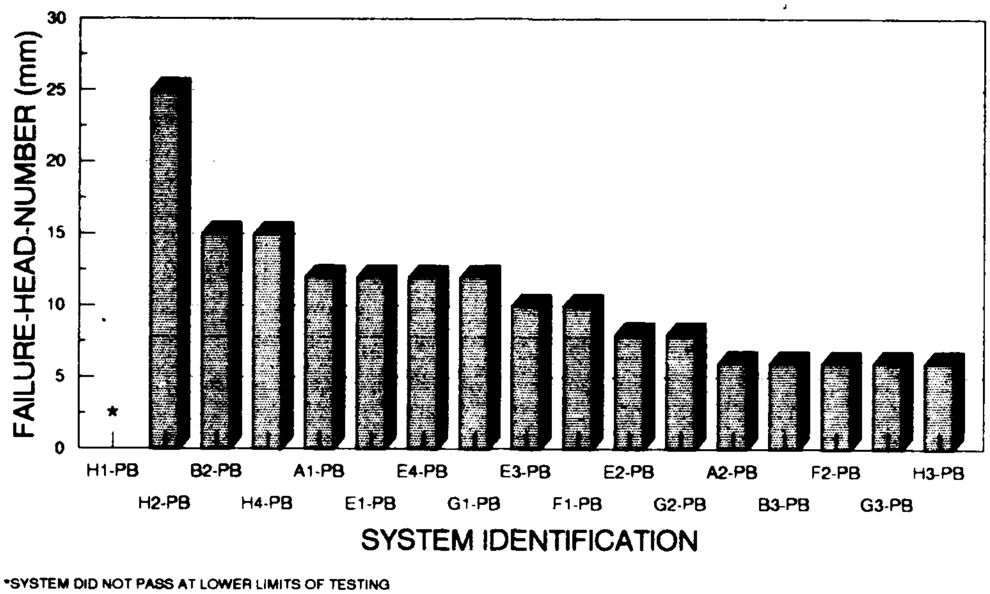


Figure 15. Failure-Head-Numbers for the European Perfotest Using Standard Failure Criterion on Class PB EIFS.

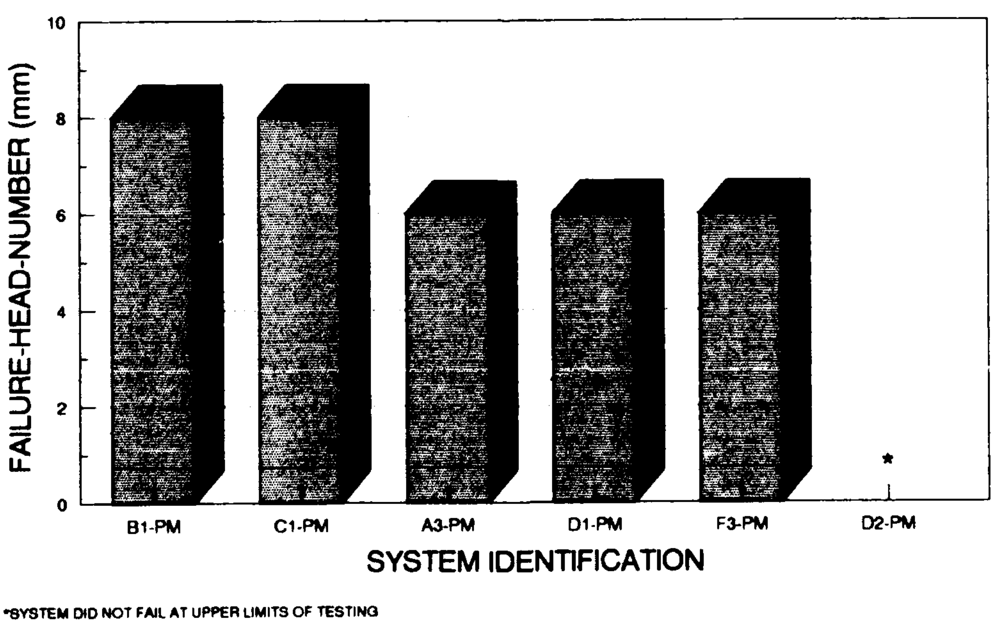


Figure 16. Failure-Head-Numbers for the European Perfotest Using Standard Failure Criterion on Class PM EIFS.

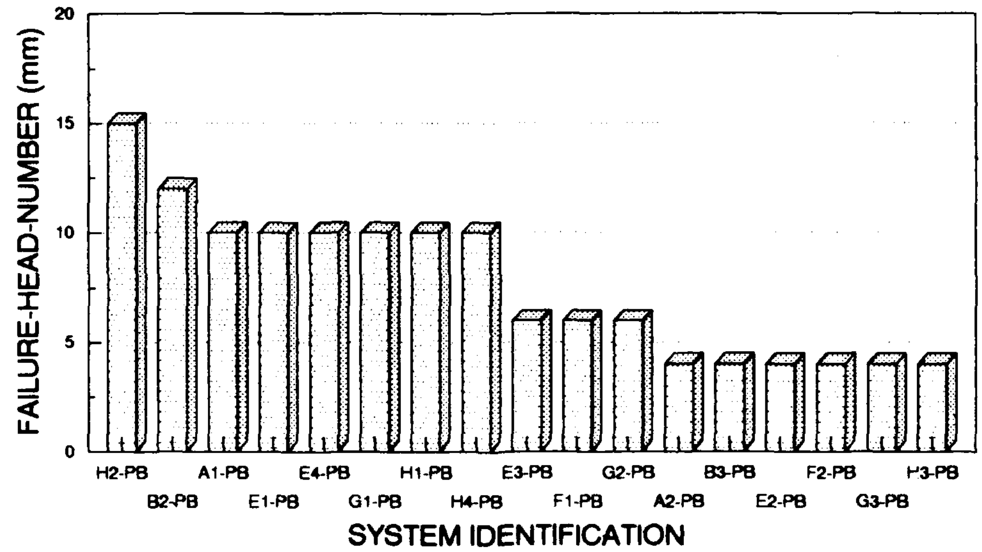


Figure 17. Failure-Head-Numbers for the European Perfotest Using Refusal Failure Criterion on Class PB EIFS.

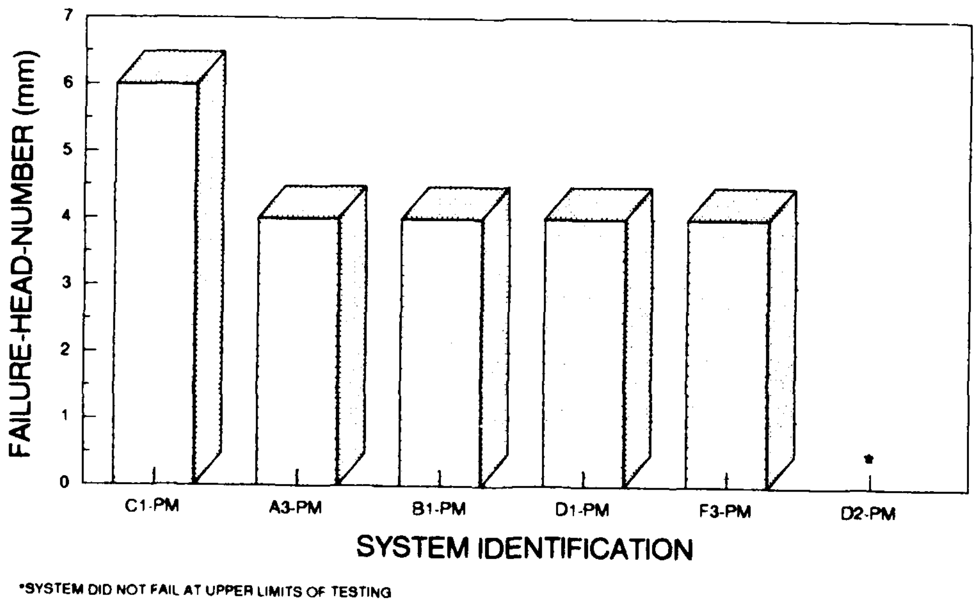


Figure 18. Failure-Head-Numbers for the European Perfotest Using Refusal Failure Criterion on Class PM EIFS.

4 DISCUSSION

The purpose in conducting these impact tests on EIFS was to determine the validity of each test for use with the systems. To do this, it is necessary to use common knowledge of these systems and make some intelligent assumptions.

EIFS are composite systems that rely on several components working together to achieve optimum performance. In terms of system strength, or impact resistance, the base coat is the component that determines this property. To make assumptions about the impact resistance of a given EIFS, you must look at how the individual components of the base coat combine. The makeup of the components in the base coat can reveal clues about the strength and impact resistance of the base coat.

In class PB EIFS, two factors make a difference in the impact resistance: (1) the type of reinforcement and (2) the chemical composition (cementitious or synthetic) of the base coat. Of the class PB systems tested, four different combinations of reinforcing fabric were used (the makeup of each class PB is given in Table 1). They are as follows:

1. One layer of standard mesh,
2. Two layers of standard mesh,
3. One layer of standard mesh and one layer of high impact mesh, and
4. Two layers of high impact mesh.

The chemical composition of the base coat is either cementitious or synthetic (all polymer).

From this information, some assumptions about the relative impact resistance of class PB systems can be made. These assumptions are as follows:

1. A class PB system with two layers of standard reinforcing mesh has a greater impact resistance than one with a single layer of reinforcing mesh.

2. A class PB system with one layer of standard reinforcing mesh and one layer of high impact reinforcing mesh has a greater impact resistance than one with either one or two layers of standard reinforcing fabric.

3. A class PB system with two layers of high impact reinforcing mesh has a greater impact resistance than the other three combinations listed above.

4. Assumptions 1-3 are more valid when comparing class PB systems within a single manufacturer than when comparing class PB systems between different manufacturers.

5. A class PB system with a synthetic base coat will have a greater impact resistance than one with a cementitious base coat, provided the reinforcement and thickness are the same.

6. A class PB system with a thicker base coat will have a greater impact resistance than one with a thinner base coat, provided the reinforcement and chemical composition are the same.

Class PM EIFS have fewer variables controlling the properties of the base coat than class PB systems. The reinforcement mesh in class PM systems serves more to key the base coat to the insulation than to reinforce the base coat. Also, while the base coat of the different class PM systems may have chemical composition differences, they all are cementitious. This makes differences between the systems

harder to quantify; the only quantifiable difference is the base coat thickness. Therefore, the main assumption one can make with class PM EIFS is that a thicker base coat increases the impact resistance.

Using the above assumptions, researchers compared the experimental results to what would be expected for each of the different test methods. This analysis was to help determine the most valid method(s) for EIFS.

Gardner, 2- and 4-lb

The first concern in using the Gardner impact test is the difference between using the 2-lb and 4-lb weight. For many materials, the rate of loading in an impact test can make a difference in the results. Therefore, the difference in the rate of loading for the 2-lb and 4-lb weights were examined. For a given impact energy, the drop height for the 2-lb weight would need to be twice as high as the drop height for the 4-lb weight. While the impact energy would be the same, the 2-lb weight would be falling 1.44 times faster than the 4-lb weight upon impact. To determine if the rate of loading was a factor between these tests, the MFEs for the 2-lb test were plotted against the MFEs for the 4-lb test as shown in Figure 19. The dotted line in this graph shows the theoretical one-to-one relationship that would be expected between the two tests if rate-of-loading were not a factor. The data points correlate very closely to the theoretical line. Therefore, it appears to make little difference whether the 2-lb or the 4-lb weight is used for the test. The 4-lb weight is preferred since the 2-lb weight did not provide enough energy to cause failure in all the systems.

If a test method was valid for class PB systems under the previously stated assumptions, one would expect that class PB systems would group together in terms of their type of reinforcement. Figure 20 (which is a remake of the bar graph in Figure 3 without the standard deviation) shows the MFE of class PB systems in order of increasing impact resistance. The bars are shaded according to the type of reinforcement in the base coat and show little grouping of the class PB systems according to base coat reinforcement.

For the six class PM systems tested using the 4-lb weight, the MFEs ranged from 64 in.-lb to 188 in.-lb (Figure 6). If the assumption is that base coat thickness is a dominant factor in the impact resistance for class PM systems, a plot of MFE vs base coat thickness should show a linear relationship beginning at the origin. Figure 21, in fact, shows this trend.

The MFEs for all systems tested using the Gardner test method are shown in Figure 22. This graph shows the class PB systems grouped at the low end of MFE values and the class PM systems grouped at the high end of MFE values. Figure 23, which is a plot of MFE vs base coat thickness for all the systems, shows the same trend as with just the class PM systems, indicating that the results using the Gardner apparatus for EIFS are very dependant on base coat thickness. This does not imply that the reinforcement does not have an influence on the impact resistance (e.g., H3-PB and A2-PB with high impact fabric — MFEs > 100 in.-lb); however, the influence is not predictable especially when comparing EIFS from different manufacturers.

Comparing the experimental results (4-lb Gardner test) with the stated assumptions for the class PB systems gives both supportive and contradictive information.

1. Assumption 1 states that a system with two layers of standard mesh has a greater impact resistance than a system with a single layer of reinforcing mesh. E3-PB and H4-PB have an impact resistance of more than double the single layer systems E1-PB and H2-PB, respectively.

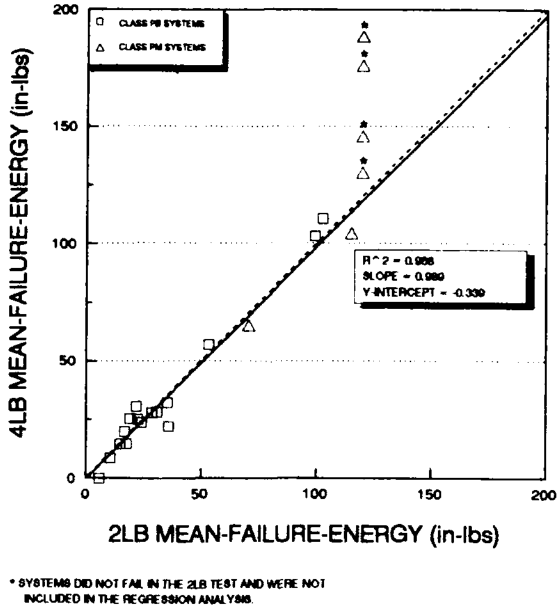


Figure 19. MFEs for the 2-lb and 4-lb Gardner Test.

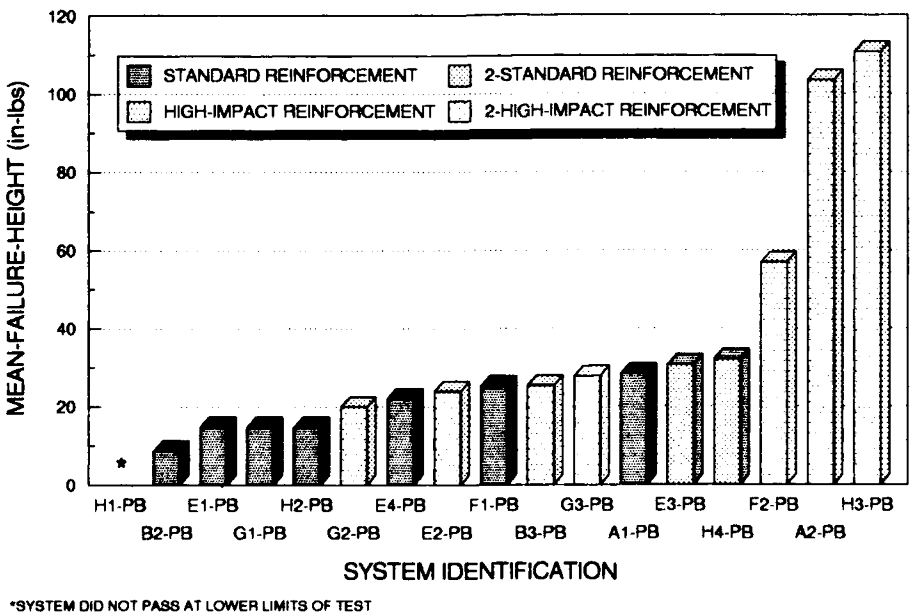


Figure 20. MFEs for the 4-lb Gardner Test on Class PB EIFS Showing Type of Reinforcement.

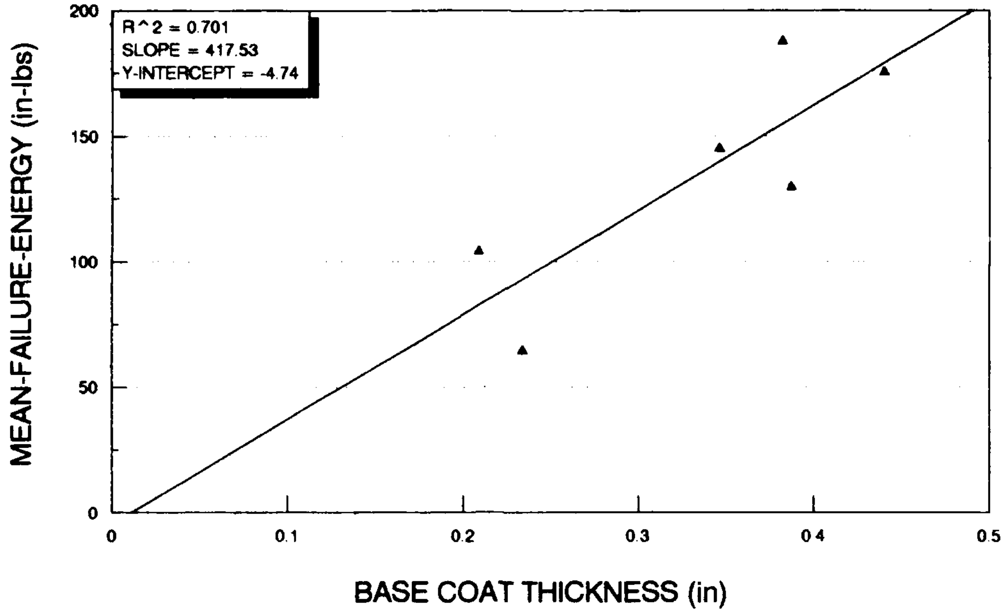


Figure 21. MFE vs Base Coat Thickness for the 4-lb Gardner Test on Class PM EIFS.

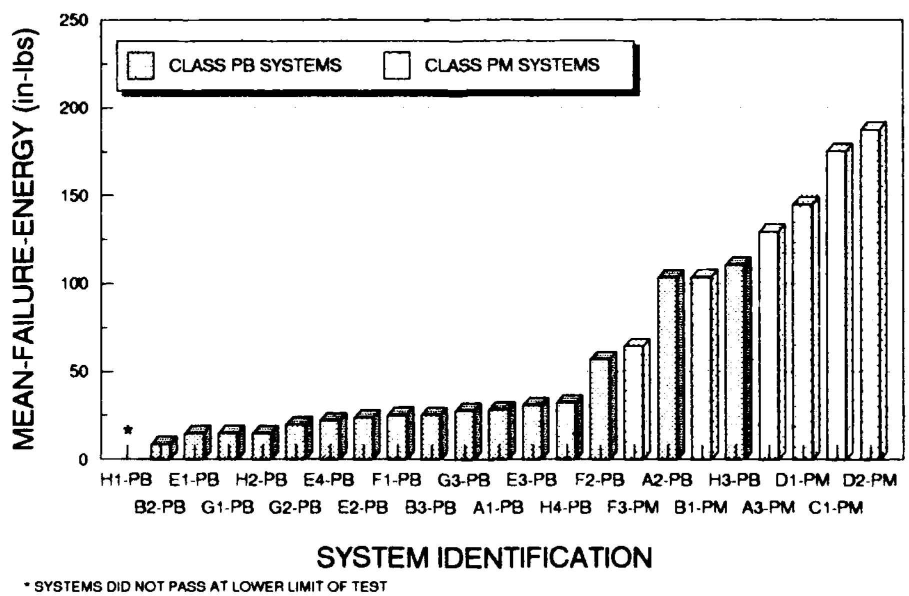


Figure 22. MFEs for the 4-lb Gardner Test on Class PB and Class PM EIFS.

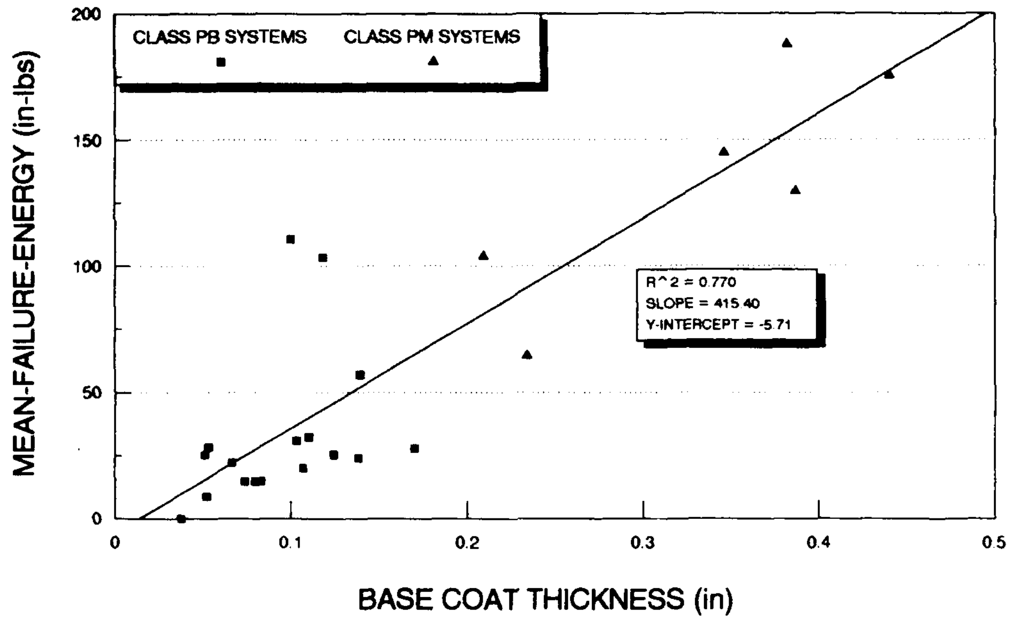


Figure 23. MFE vs Base Coat Thickness for the 4-lb Gardner Test on Class PB and Class PM EIFS.

2. Assumption 2 states that a high impact system has a greater impact resistance than a single layer or a two-layer standard mesh system. Two systems (H3-PB and A2-PB) have significantly higher impact resistances than all of the other systems regardless of the mesh system. After these two systems, the third highest system is still twice the impact resistance of the fourth highest. Still, three systems (G2-PB, E2-PB and B3-PB) have values lower than one system with a single reinforcing layer (A1-PB).

3. Assumption 3 states that systems with two layers of high impact mesh have a greater impact resistance than any of the other combinations. The only system with this construction had an impact resistance higher than the systems from the same manufacturer using a single standard layer or the standard and high impact layers, but lower than some systems from other manufacturers with a single layer and significantly lower than others with the standard high impact reinforcing mesh.

4. Assumption 4 states that the first three assumptions are most valid for the same manufacturer. As mentioned in the discussion about Assumption 3, a comparison of results shows the first three assumptions valid for the same manufacturer but not between manufacturers.

5. Assumption 5 predicts that a system with a synthetic base coat will have a greater impact resistance than one with a cementitious base coat provided the reinforcement and thickness are the same. Neither systems E4-PB nor H2-PB follow this assumption. System H2-PB even had the thickest base coat of all the single layer, standard mesh systems. System H3-PB, with a single standard and a single high impact layer of mesh in a synthetic base coat had an impact resistance six times greater than G2-PB with the same reinforcing system but a cementitious base coat. G2-PB was even slightly thicker than H3-PB. Still, system A2-PB with a cementitious base coat had an impact resistance only slightly less than H3-PB.

6. Assumption 6 states that a thicker base coat will result in a higher impact resistance given the same reinforcement and chemical composition. Although analysis of the data shows a general trend to support this assumption, several exceptions are noted. System A2-PB has almost twice the impact resistance of F2-PB while only 0.02 in. thinner than F2-PB. F1-PB and A1-PB recorded greater impact resistances than the other single layer mesh, cementitious base coat systems, yet they have significantly thinner base coats. H1-PB with a base coat thickness of 0.037 in. was obviously below some lower limit for any kind of acceptable properties.

The above discussion indicates that the variables controlling the impact resistance of class PB EIFS systems relative to the Gardner impact test method are not independent of each other. This interdependence makes the interpretation of the results difficult.

Given all the above considerations, the Gardner test method does not appear to be a very good method for predicting the impact resistance of both class PB and PM EIFS. Its generally poor correlation with system properties other than possibly thickness (most acceptable for class PM systems), limit the usefulness of the test method in predicting long-term system performance under various, real-world impact situations. However, the method can provide a relative ranking of the systems with regards to the very specific type of impact as used in the test (i.e., a puncture/penetration type impact).

Falling Ball, 2-and 4-lb

As with the Gardner test method, given the stated assumptions, one would expect to see grouping of the class PB systems relative to the type of base coat reinforcement if the MFEs were plotted in an increasing manner. Figure 24 (which is a remake of the bar graph in Figure 10 without the standard deviation) plots the results for the 2-lb falling ball test of class PB EIFS in order of increasing MFE. The bars of this graph are shaded according to the type and number of layers of reinforcing mesh. Although not perfect, a decided grouping is observed of systems with one layer of standard reinforcing mesh and of systems with one layer of standard and one layer of high impact reinforcing mesh.

Researchers assumed, that the base coat thickness is also a prime factor influencing impact resistance of class PM systems. Figure 25 is a plot of MFE vs base coat thickness for the six class PM systems. The results, however, do not give as clear an indication (as they did with the Gardner test) that the impact resistance of these class PM systems are thickness controlled (i.e., the correlation [R^2] was 0.703 for the plotted results from the Gardner test but only 0.258 for results from the falling ball test) because there were only six data points.

To determine if any relationship exists for class PB systems relative to base coat thickness, MFEs were plotted vs base coat thicknesses for the class PB systems in Figure 26. The results show a trend that has an x-intercept of approximately 0.046 in. Physically, this has some meaning. The base coat properties become discontinuous at the thickness of the reinforcement mesh since the lamina cannot be thinner than the mesh. Standard mesh thicknesses range from 0.015 to 0.022 in. If there were no base coat thickness over the mesh, a failure could not be defined since no cracking could be observed. Although thickness may have some influence, it does not appear to be the predominant factor regarding the impact resistance for class PB systems. Figure 27 is a plot of MFE vs thickness for both class PB and class PM systems. The results emphasize the above statement that thickness is not the predominant factor influencing the test results.

Figure 28 shows all the systems in increasing order of MFE for both the 2-lb and 4-lb falling ball impact test. The MFE results range from less than 1.7 ft-lb to greater than 60.0 ft-lb.

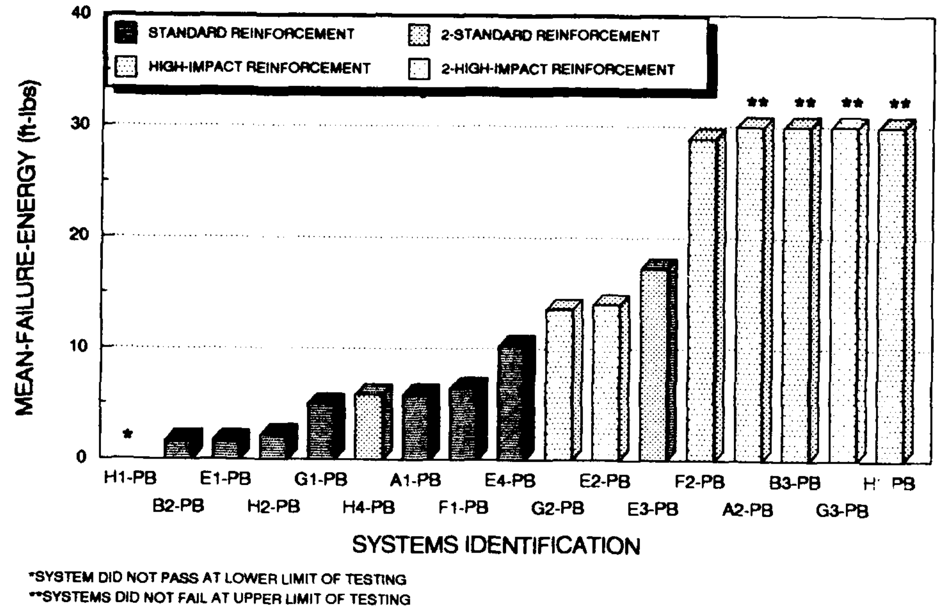


Figure 24. MFEs for the 2-lb Falling Ball Test on Class PB EIFS Showing Type of Reinforcement.

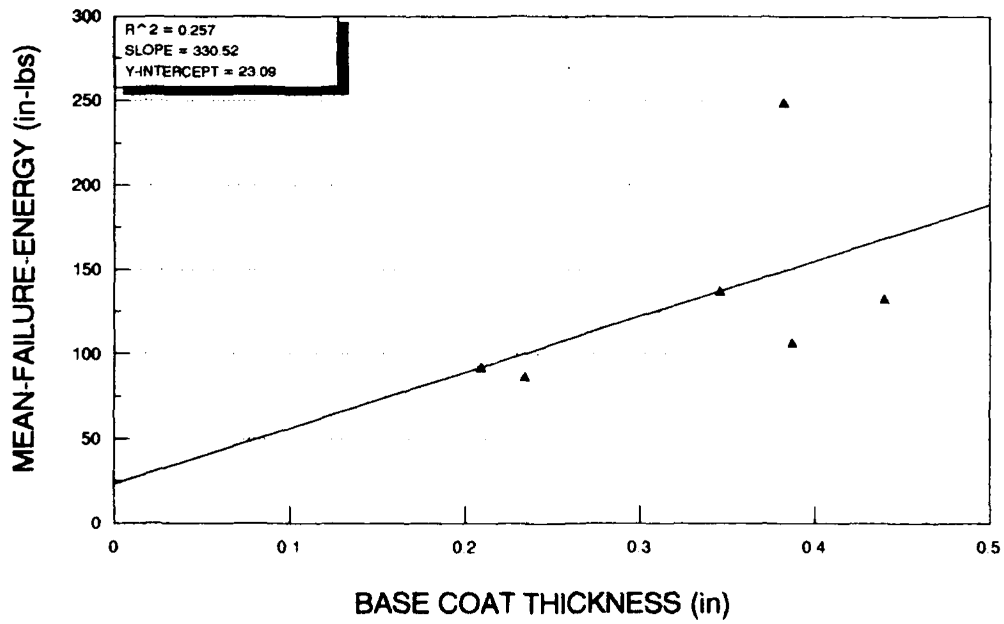


Figure 25. MFE vs Base Coat Thickness for the 2-lb Falling Ball Test on Class PM EIFS.

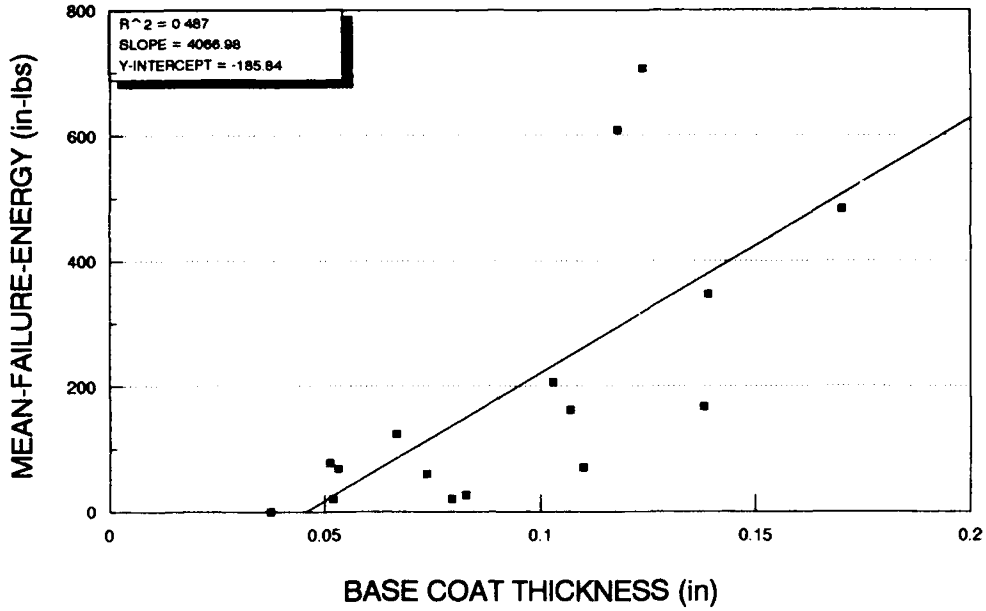


Figure 26. MFE vs Base Coat Thickness for the 2-lb and 4-lb Falling Ball Test on Class PB EIFS.

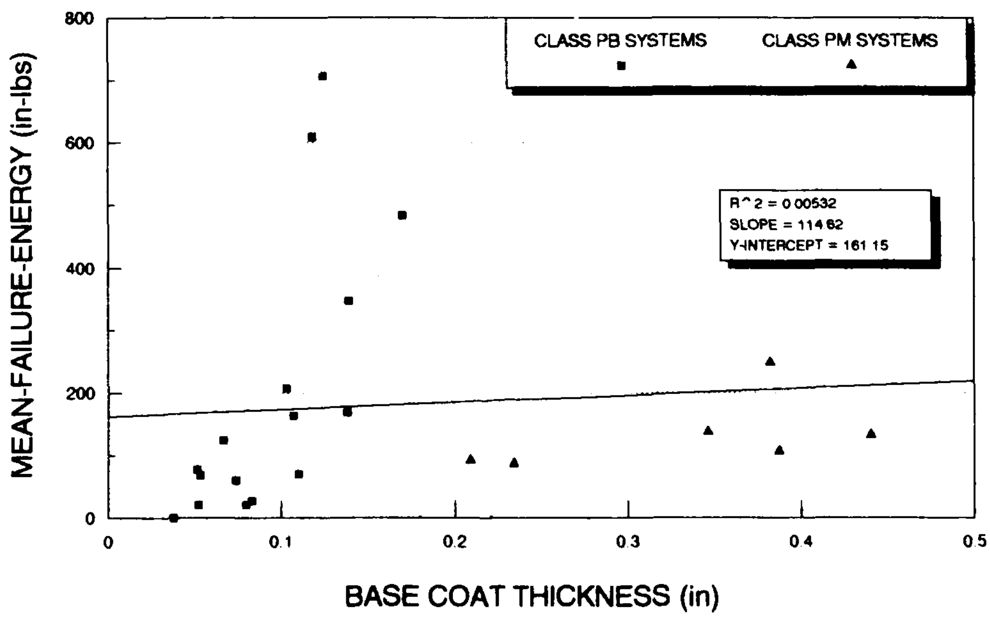


Figure 27. MFE vs Base Coat Thickness for the 2-lb and 4-lb Falling Ball Test on Class PB and Class PM EIFS.

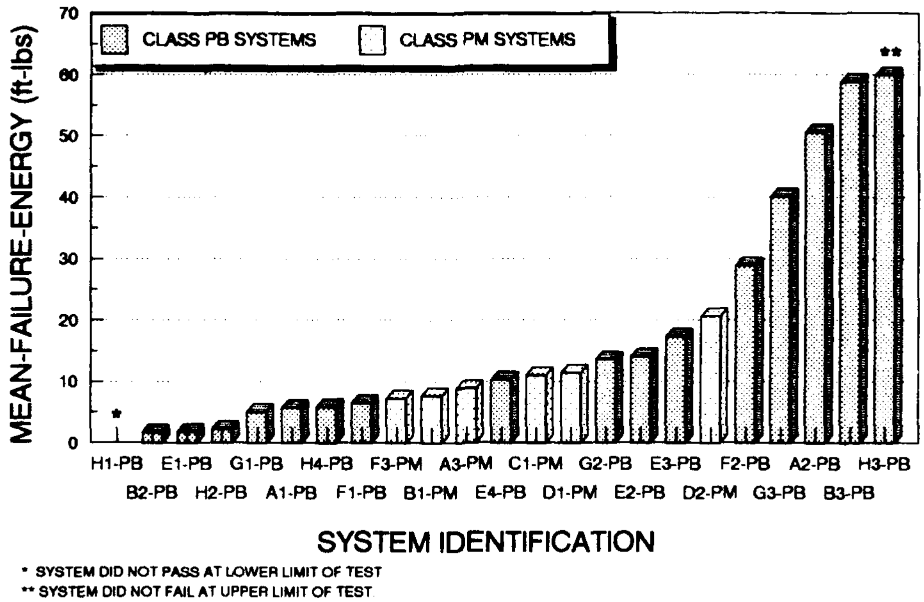


Figure 28. MFEs for the 2-lb and 4-lb Falling Ball Test on Class PB and Class PM EIFS.

As with the Gardner test, the experimental results for class PB systems using the falling ball test method were compared to the assumptions. Although generally more supportive, compared to the Gardner test, both supportive and contradictive results are again shown.

1. Assumption 1 states that a system with two layers of standard mesh has a greater impact resistance than a system with a single layer of reinforcing mesh. System E3-PB with a double layer of standard mesh had a greater impact resistance than any of the single layer standard mesh systems. System H4-PB, on the other hand, is in the middle of the range.

2. Assumption 2 states that a high impact system has a greater impact resistance than a single layer or a two-layer standard mesh system. Four of the six systems with the single standard and single high impact meshes have a higher impact resistance than the single standard or double standard meshes. The two systems not following this trend are G2-PB and E2-PB.

3. Assumption 3 states that systems with two layers of high impact mesh have a greater impact resistance than any of the other combinations. System G3-PB had a greater impact resistance than systems F2-PB, E2-PB, and G2-PB but still less than A2-PB, B3-PB, and H3-PB, all with the single layer of high impact mesh.

4. Assumption 4 states that the first three assumptions are more valid for the same manufacturer. This assumption holds true except for system E3-PB with two layers of standard mesh, which had an impact resistance slightly higher than system E2-PB with a single standard plus a single high impact mesh. System B2-PB was next to the lowest impact resistance at 1.68 ft-lb while system B3-PB was next to the highest at 58.88 ft-lb.

5. Assumption 5 predicts that a system with a synthetic base coat will have a greater impact resistance than one with a cementitious base coat, provided the reinforcement and thickness are the same. For the single standard mesh systems, system E4-PB with a synthetic base coat had the highest impact resistance. Its thickness was only slightly greater than half of the systems tested. H2-PB, also a synthetic base coat system, had an impact resistance significantly lower than E4-PB even though H2-PB had the greatest thickness of all the single standard mesh systems.

6. Assumption 6 states that a thicker base coat will result in a higher impact resistance given the same reinforcement and chemical composition. Although analysis of the data shows a general trend to support this assumption, as with the Gardner test, exceptions are noted. Systems A2-PB and F2-PB had almost the same impact resistance even though A2-PB was 0.02 in. thinner. System H1-PB with a base coat thickness of 0.037 in. was obviously below some lower limit for any kind of acceptable properties.

The above discussion again indicates that the variables controlling the impact resistance of class PB EIFS systems as determined by the falling ball test are not completely independent of each other. Still, the assumptions predict the falling ball results closer than they do for the Gardner test.

The test results from the falling ball method generally reflect the postulated controlling factors of class PB systems. Although the correlation of the results to system composition for class PM systems is not as good as desired, the falling ball method simulates the geometry and forces of many real-world impacts (e.g, baseball or large rock). Therefore, the falling ball test is considered a practical method for measuring impact resistance for all EIFS.

Perfotest

Similar to the other test methods, the data using the standard failure criterion were plotted in order of decreasing head number (this is an increasing impact resistance) to see if the class PB systems are grouped together relative to the type of base coat reinforcement (Figure 29). Determining the point of failure was harder to judge using the refusal failure criteria than the standard failure criteria. However, since the refusal failure criteria results were almost always one head smaller than the standard failure criteria results, only the standard failure criteria was considered for further analysis of the test results. The bars of the graph in Figure 29 are shaded according to the type and number of layers of reinforcing mesh. A grouping of systems with one layer of standard reinforcing mesh and of systems with one layer of standard plus one layer of high impact reinforcing mesh is seen. Based on these observations, one can conclude that the Perfotest impact test has some validity for use with class PB EIFS.

For the class PM systems, conclusions are more difficult to draw. The results from the Perfotest are in discrete increments. With only six specimens of basically similar composition and the incremental nature of the test, the test results were naturally very close (see Figure 14). Two specimens failed with an 8-mm head, three with a 6-mm head, and one did not fail at the upper limits of the test (4-mm head).

Because successful, nondamaging impact of decreasing head size indicates greater impact resistance, the Perfotest results display inversely of the results from the other two methods. Plotting both the class PB and PM systems vs standard failure criterion gives a graph as shown in Figure 30. With some simple calculations taking into consideration the applied force and the impact area of the different heads, the failure head number results were changed into energy per unit area (Tables 10 and 11). A plot of the recalculated information is given in Figure 31. Now, the taller the bar, the greater the impact resistance giving us a more direct comparison to the results from the other methods.

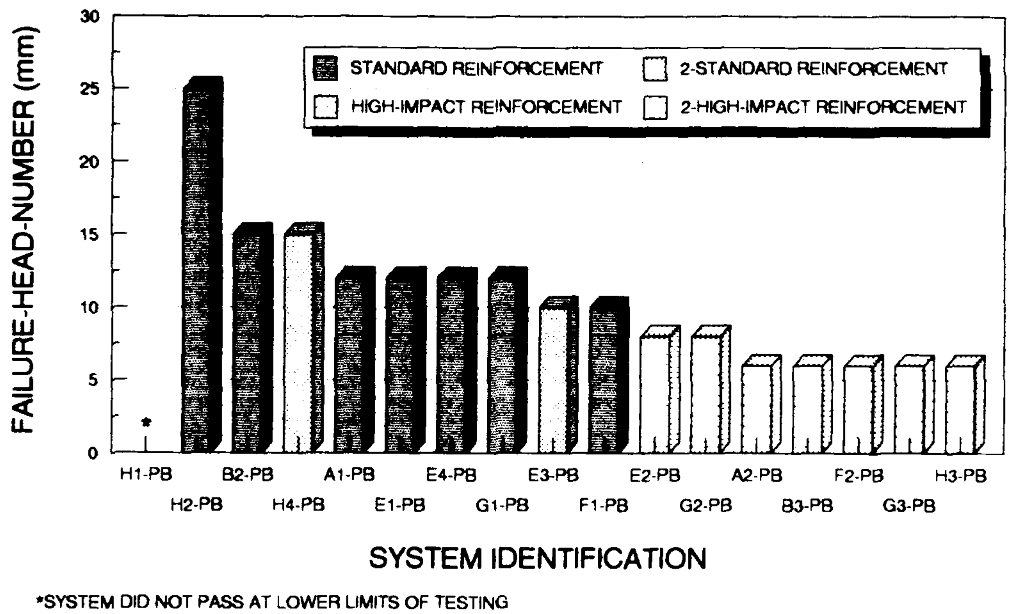


Figure 29. Failure-Head-Numbers for the European Perfotest on Class PB EIS Showing Reinforcement Type.

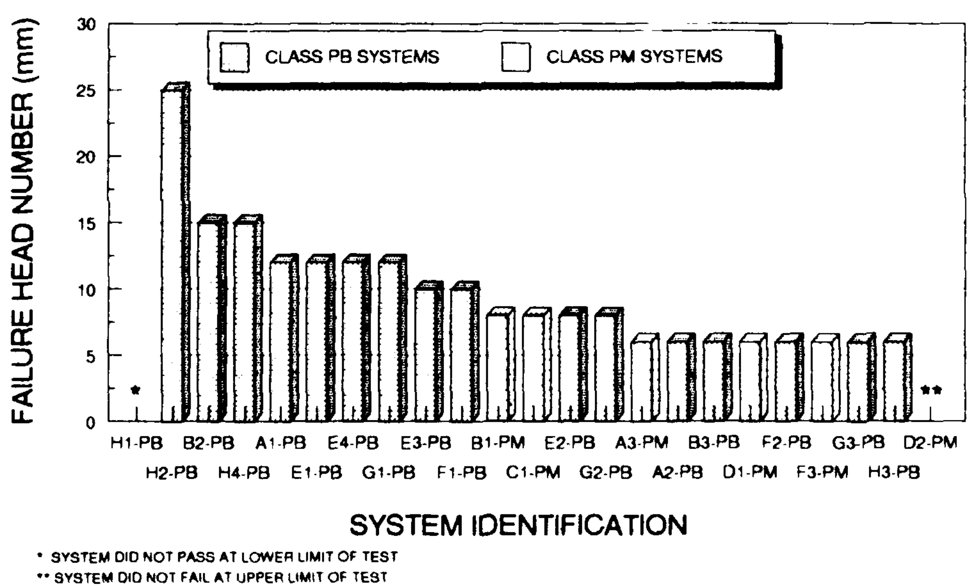


Figure 30. Failure-Head-Numbers for the European Perfotest on Class PB and Class PM EIFS.

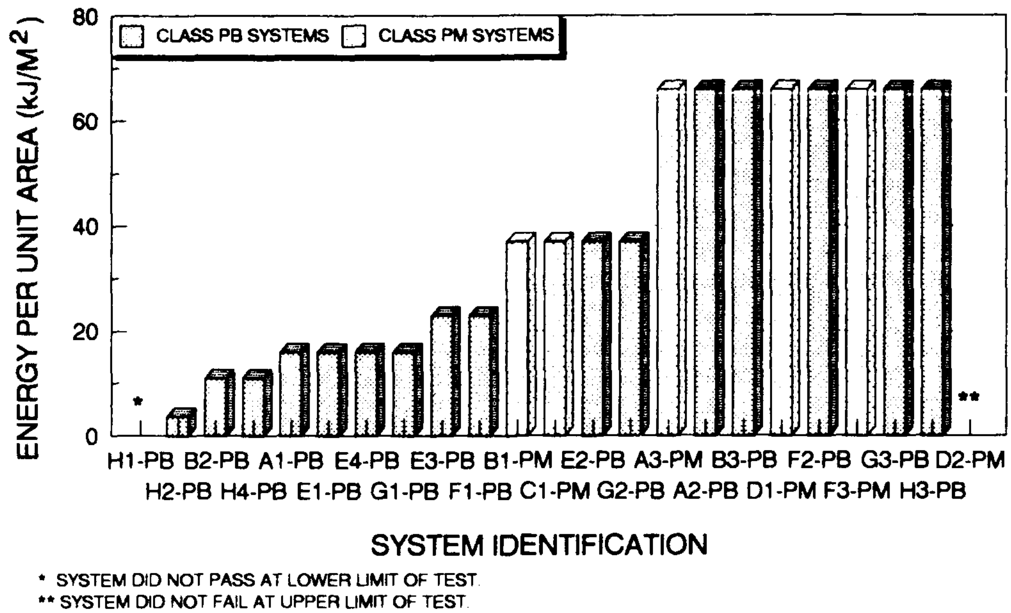


Figure 31. Energy per Unit Area for the European Perfotest on Class PB and Class PM EIFS.

To determine if there is any relationship of the results with base coat thicknesses for either the class PB or PM systems, the energy per unit area was plotted vs base coat thickness (Figure 32). No apparent relationship for either system class is indicated. For example: four class PB systems with base coat thicknesses slightly less than 0.118 in. had an energy per unit area between 12 kJ/m^2 to 66 kJ/m^2. Looking at it from another perspective, eight systems with an energy per unit area of 66 kJ/m^2 had base coat thicknesses ranging from slightly less than 0.118 in. to slightly greater than 0.354 in. Thickness does not appear to be a dominant factor affecting the impact results.

As with the other two test methods, a comparison of experimental results with the stated assumptions is made for the Perfotest apparatus.

1. Assumption 1 states that a system with two layers of standard mesh has a greater impact resistance than a system with a single layer of reinforcing mesh. As shown in the other test methods, system E3-PB had a greater impact resistance than E1-PB. H4-PB also had a greater impact resistance than H2-PB. However, H4-PB had an impact resistance less than five other systems with a single standard mesh.

2. Assumption 2 states that a high impact system has a greater impact resistance than a single layer or a two-layer standard mesh system. The results support this assumption.

3. Assumption 3 states that systems with two layers of high impact mesh have greater impact resistance than any of the other combinations. No class PB system had a higher impact resistance value than G3-PB with its double, high impact mesh. However, the value was the same as four other systems with high impact fabric.

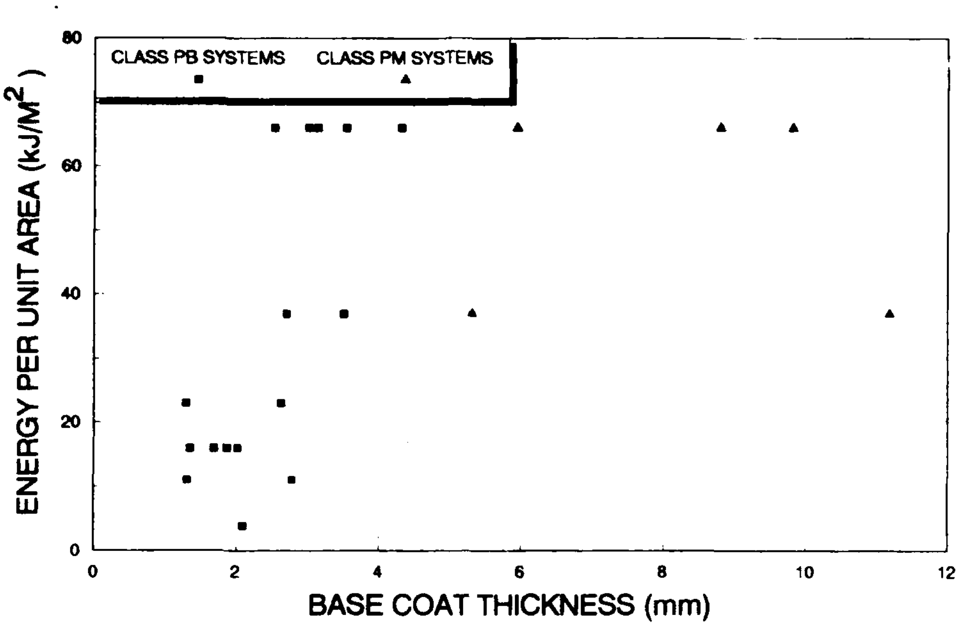


Figure 32. Energy per Unit Area vs Base Coat Thickness for the European Perfotest on Class PB and Class PM EIFS.

4. Assumption 4 states that the first three assumptions are more valid for the same manufacturer. Within the limitation of the incremental nature of the results, this assumption is supported by the experimental results.

5. Assumption 5 predicts that a system with a synthetic base coat will have a greater impact resistance than one with a cementitious base coat, provided the reinforcement and thickness are the same. System F1-PB had one level higher impact resistance than E4-PB even though F1-PB was 0.02 in. thinner. H2-PB, another single-layer mesh, synthetic base coat system, was next to the worst impact resistance even though it had the greatest thickness of all the single mesh systems. H4-PB had an impact rating two increments lower than E3-PB. System H3-PB was rated better than two other high impact mesh systems but the same as three others. A synthetic base coat did not seem to help the impact resistance much as measured by the Perfotest.

6. Assumption 6 states that a thicker base coat will result in a higher impact resistance given the same reinforcement and chemical composition. How the results conform to this assumption is not very obvious. Several systems with varying thicknesses had the same impact resistance value. This is due to the incremental nature of the results.

Although the results as a whole support the assumptions made, the discrete, incremental results make exact correlation difficult.

Based on the previous discussion, the Perfotest appears to give logical results based on system composition and expected properties. Its validity is limited by the incremental nature of the results.

Methods Comparison

After evaluating each method separately it is important to see how the methods compare to each other. Table 12 is a tabulation of the systems showing their relative ranking based on impact resistance as determined by each test method; #1 equals the highest impact resistance and #23 the lowest impact resistance. The Perfotest results are grouped together to account for the incremental results of the method. For the most part, the 2-lb and 4-lb Gardner test results gave a similar ranking. However, the rankings from the Gardner test method do not correlate very well with the rankings from the falling ball method. As best as can be expected due to the incremental nature of the test results, the Perfotest rankings show some correlation with the falling ball test rankings. Actually, each test method identified the worst systems and ranked them nearly the same. System H1-PB ranked #23 by every method; system B2-PB ranked #22. At the other end of the spectrum, system D2-PM was ranked #1 by three different methods (including the 1 to 4 ranking by the 2-lb Gardner—no failure using the 2-lb weight at the maximum drop height of the apparatus) and #6 by the falling ball. In other cases, correlation between test methods is not always obvious especially since the Perfotest rankings are grouped. The falling ball method tends to rank the class PM systems lower than the Gardner or Perfotest methods.

Looking at the methods from an operational viewpoint, the Perfotest is the simplest and easiest to perform, the Gardner the next, and the falling ball the most involved to perform. Even though the Perfotest is so easy to use, the incremental results are not considered precise enough for a laboratory test. As a screening device or a quality control/assurance tool, the Perfotest is adequate; it is not for research or product development. Besides the incremental results, another criticism of the Perfotest is the variable area of the striker. By nature of the device, the energy of impact is the same but the energy per unit area is changed by increasing or decreasing the size of the impacting head. The full ramifications of this geometry change are not known; however, the change in area does raise some concerns. A set geometry for the indentor probably yields more accurate results by eliminating a variable that may behave differently with different system reinforcing meshes and chemical compositions.

The Gardner test, although relatively simple and easy to use, does not provide true impact resistance values for the system but rather puncture/penetration resistance values. The thicker, harder systems will perform better with this method. Its poor correlation with the overall system properties limit its usefulness as a method for predicting long-term impact resistance for EIFS as a whole (combined class PB and PM systems).

The falling ball test method is by far the most troublesome of the tests to perform. A high ceiling, open area is needed to provide the drop height distances and clearance for the swinging ball. A sturdy frame or wall for specimen attachment is also needed. Even with these drawbacks, the falling ball method is considered the best of the methods evaluated to determine true impact resistance of EIFS. The geometry of the test comes closer to simulating the action of a baseball or large rock being hurled at the wall, a suitcase bumping against the wall, or even someone kicking the wall.

Table 12

Relative Ranking by Test Method*

System ID	Gardner Test		Falling Ball	Perfotest STD Criterion
	2-lb	4-lb		
A1-PB	12	12	17	16-19
A2-PB	7	7	3	2-9
A3-PM	1-4	4	13	2-9
B1-PM	5	6	14	10-13
B2-PB	22	22	22	20-21
B3-PB	17	14	2	2-9
C1-PM	1-4	2	11	10-13
D1-PM	1-4	3	10	2-9
D2-PM	1-4	1	6	1
E1-PB	18	21	21	16-19
E2-PB	14	16	8	10-13
E3-PB	16	11	7	14-15
E4-PB	10	17	12	16-19
F1-PB	15	15	16	14-15
F2-PB	9	9	5	2-9
F3-PM	8	8	15	2-9
G1-PB	20	20	19	16-19
G2-PB	19	18	9	10-13
G3-PB	13	13	4	2-9
H1-PB	23	23	23	23
H2-PB	21	19	20	22

*1 is the highest impact resistance; 23 is the lowest.

5 CONCLUSIONS AND RECOMMENDATIONS

Of the three test methods for impact resistance evaluated in this research (falling weight, falling ball, and Perfotest), the falling ball method is the best for assessing the overall impact resistance of EIFS. This conclusion is drawn from a comparison of the test results and postulated properties for each system based on the physical and chemical composition.

Each of 23 different EIFS systems were tested using the three different test methods. Selected variances in the test methods were also examined (2-lb and 4-lb falling weight). The test results indicate the falling weight or Gardner test did not give very good correlation of results with system properties designed to increase impact resistance. The Gardner test method is better for testing the puncture resistance of systems rather than the impact resistance. The Perfotest method is a good field test method, but due to the incremental nature of the results, the method is not well suited for laboratory use. The falling ball test method, although more troublesome than the other two, is the best of the methods evaluated for assessing the overall impact resistance of EIFS.

1. A falling ball test method should be adopted by ASTM to determine the impact resistance of EIFS.

a. A draft test method, "Resistance of Exterior Insulation and Finish Systems (EIFS) to Rapid Deformation (Impact) by Means of a Falling Ball", was submitted to ASTM Committee E-06.55 on Performance of Building Constructions, Exterior Walls in the fall of 1990 for further development and possible adoption by ASTM as a standard test method. A copy of this draft method is included in Appendix A.

b. Several questions remain to be answered or agreed upon: specimen design, specimen support, lighting requirements, definition of failure and reproducibility of results (especially between different laboratories. It is anticipated that the ASTM Committee will help answer some of these questions and get a meaningful impact test method for EIFS in place.

2. Besides an impact test method, a puncture test method for EIFS is also needed. Even though the Gardner test method is not considered a good impact resistance test method for EIFS, it appears to be an excellent puncture resistance test method for EIFS and should be adopted as such by ASTM.

3. The Perfotest should also be adopted by ASTM as a field screening method, at least until a better field portable method is developed. Much work is envisioned establishing uniform procedures for field testing and correlation to any adopted impact and puncture resistance test methods.

4. As these methods are adopted, performance standards for the different classes of EIFS will need to be established. EIFS systems should be rated for both impact and puncture resistance. Performance requirements will be needed to differentiate between standard and high impact and puncture resistant systems as needed depending on the application and location.

5. Test methods and performance standards adopted by ASTM should be incorporated into future updates of Corps of Engineers Guide Specification CEGS-07240, *Exterior Insulation and Finish Systems.*

METRIC CONVERSION TABLE

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 lb	=	0.453 kg

REFERENCES

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ASTM D2794-90, "Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)," *Annual Book of ASTM Standards*, Vol 06.01 (ASTM, 1991), pp 404-405.

ASTM D3029-90, "Standard Test Methods for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Tup (Falling Weight)," *Annual Book of ASTM Standards*, Vol 08.02 (ASTM, 1991), pp 517-528.

CEGS-07240, *Exterior Insulation and Finish Systems* (Headquarters, U.S. Army Corps of Engineers [HQUSACE], December 1988.)

EIMA Test Method & Standard 101.86, *Standard Test Method for Resistance of Exterior Insulation Finish Systems to the Effects of Rapid Deformation (Impact)*, EIMA Guideline Specification for Exterior Insulation and Finish Systems-Class PB Type A, Appendix A, April 1987.

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Smith, A., R.E. Muncy, and S.C. Sweeney, *Criteria for Evaluating Impact Damage Resistance of Exterior Insulation and Finish Systems*, Technical Report M-335/ADB079523 (U.S. Army Construction Engineering Research Laboratory [USACERL], November 1983).

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APPENDIX A: Draft ASTM Test Method

DRAFT TEST METHOD
ASTM EIFS COORDINATING COMMITTEE

ASTM DESIGNATION: P ----

Standard Test Method for
RESISTANCE OF EXTERIOR INSULATION AND FINISH SYSTEMS (EIFS) TO RAPID DEFORMATION (IMPACT) BY MEANS OF A FALLING BALL

1. Scope

1.1 This test method covers a procedure for rapidly deforming by impact from a falling ball, Exterior Insulation and Finish Systems (EIFS). This test method was developed to test both of the two main classes of EIFS; polymer based (Class PB) systems and polymer modified (Class PM) systems.

1.2 This test method should be used to determine the impact resistance of both Class PB and Class PM EIFS.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards*:
D3029 Methods for Impact Resistance of Rigid Plastic Sheeting or Parts by Means of a Tup (Falling Weight)[1]

3. Summary of Test Method

3.1 The EIFS to be tested are applied to test frames designed to imitate common construction practices and substrates. After the EIFS have cured, they are rigidly attached vertically to a fixed support system. Each EIFS is then impacted by a falling steel ball in a stair-step fashion. The test data are analyzed to determine a mean-failure-energy. The resistance to impact of the EIFS can then be classified according to specified performance criteria.

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[1] *Annual Book of ASTM Standards*, ASTM D3029-90, "Standard Test Methods for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Tup (Falling Weight)" Vol 08.02 (American Society of Testing and Materials [ASTM], 1991).

4. Significance and Use

4.1 This test method covers the determination of the resistance to impact of EIFS by a falling ball. This information should be useful for the following:

4.1.1 Aiding manufacturers in the development of EIFS with improved resistance to impact.

4.1.2 Aiding architects/engineers in specifying EIFS which meet performance criteria necessary for long term building integrity.

5. Apparatus

5.1 The falling ball apparatus employs a 2 lb steel ball with a 2-3/8 inch diameter. This ball is suspended by a 30 ft length of Kevlar^R cord. The support for the steel ball and cord must be able to move up-and-down, side-to-side, and front-to-back. The mass of the support must be sufficient to act as a stationary point for the pendulum. Vertical steel columns with horizontal supports shall be set up below where the ball and Kevlar^R cord are supported. The test panel is to be rigidly secured to these columns. The support for the steel ball shall be moved so that the ball will strike the test panel at the bottom of its swing.

6. Test Specimens

6.1 The EIFS shall be applied over 4 ft. by 8 ft. test frames. These frames should be made from standard 2x4 lumber or steel studs with a 16 inch center-to-center stud spacing. This frame should be covered with a 4 ft. by 8 ft. sheet of 1/2 inch gypsum sheathing board. The EIFS shall be applied over this panel per each manufacturers installation requirements.

6.2 The EIFS shall be applied over 1 inch thick insulation board which is common to that system. The specimens shall be allowed to cure for at least 28 days at 73.4F+/-3 and 50 +/- 5% relative humidity.

7. Procedures

7.1 The test frame with the EIFS applied to it must be rigidly attached to the steel columns of the test apparatus. This can be accomplished by screwing the frame tightly against the steel columns using lag screws.

7.1.2 In order to be able to see where the panel should be impacted, a grid should be placed on the surface of the EIFS. This can be accomplished using a chalk line. The grid should be made up of 6 inch squares.

7.1.3 Strike the panel with the steel ball from a height lower than that which is expected to cause failure. If no failure occurs, raise the height by 3 inches and impact the panel again at a new impact site. Continue increasing the drop height on successive impacts until a failure occurs. When a failure occurs decrease the drop height by 3 inches on the successive impact. Continue this up-and-down procedure,increasing the drop height after passes and decreasing the drop height after failures, until at least 25 impacts have been recorded starting with the first failure. Impact points must be at least 6 inches apart and 6 inches from the edges of the panel.

7.1.4 A failure is defined as any crack visible to the naked eye under ordinary lighting.

8. Calculations

8.1 A mean-failure-energy is determined using methods outlined in ASTM D 3029. The first step in calculating a mean-failure-energy is to calculate a mean-failure-height. The mean-failure-height is calculated using the following formula:

$$h = h_o + d_h(A/N \pm 0.5)$$

where:

h = is the mean-failure-height,
h_o = is the lowest height at which an event occurred,
d_h = is the increment in drop height,
N = is the total number of failures or non-failures, whichever is smaller (Whatever is used, either failure or non-failure is called an event.),
A = is given by the expression,

$$A=\sum_{i=0}^{k} in_i,$$

where:

i = 0,1,2....k (a counting index starting at h_o),
n_i = is the number of events that occurred at h_i, and
h_i = is given by the expression,

$$h_i = h_o + id_h.$$

In calculating the mean-failure-height, h, the negative sign is used when the events are failures and the positive sign is used when the events are non-failures.

8.1.2 The estimated standard deviation of the sample is calculated using the following formula,

$$S_h = 1.62d_h[B/N-(A/N)^2] + 0.047d_h.$$

where:

B = is given by the expression,

$$B = \sum_{i=0}^{k} i^2 n_i$$

This formula is valid only if $[B/N-(A/N)^2] > 0.3$.

8.1.3 The estimated standard deviation of the sample mean failure height is given by the following expression,

$$S_{hbar} = G * S_h/\sqrt{N}$$

where:

S_{hbar} = is the estimated standard deviation of the mean failure height,
G = is a function of S_h/d_h. (Values for G can be found in D3029)

8.1.4 The mean-failure-energy, MFE, can be calculated using the following formula,

$$MFE = h * w$$

where:

MFE = is the mean-failure-energy,
h = s the mean-failure-height,
w = is the constant drop weight used in testing.

8.1.5 The estimated standard deviation of the mean-failure-energy is given by the following formula,

$$S_{MFE} = S_{hbar} * w.$$

9. Precision and Bias

9.1 No statement is made on the precision or bias of this test method since no data are available at this time based on the use of this test method.

APPENDIX B: Sample Calculations

Drop Height (in)	Outcome of Test (P_o = Pass; N_x = Failure)															n_x	n_o	i	n_i	in_i	i^2n_i
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
10	P_o															0	1				
11		P_o						P_o								0	2				
12			P_o		P_o		F_x		P_o						P_o	1	4	0	1	0	0
13				F_x		F_x				P_o		P_o		F_x		3	2	1	3	3	3
14											F_x		F_x			2	0	2	2	4	8
15																0	0	3			
16																0	0				
																6 (N_x)	9 (N_o)		6 (N)	7 (A)	11 (B)

The mean-failure-height, MFE, is calculated using the following formula;

$$h = h_o + d_h\,(A/N - 0.5)$$

$$h = (12\text{in.}) + (1\text{in.})(7/6 - 0.5)$$

$$h = 12.667 \text{ in.}$$

The estimated standard deviation, S_h, of the sample is calculated using the following formula;

$$S_h = 1.62\, d_h\, [B/N - (A/N)^2] + 0.047\, d_h$$

$$S_h = 1.62\ (1 \text{ in.})\ [11/6 - (7/6)^2] + 0.047\ (1 \text{ in.})$$

$$S_h = 0.812 \text{ in.}$$

The estimated standard deviation of the sample mean-failure-height, S_{hbar}, is calculated using the following formula;

$$S_{hbar} = \frac{(G \times S_h)}{\sqrt{N}}$$

$$S_{hbar} = \frac{(1.025 \times 0.812 \text{ in.})}{\sqrt{6}}$$

$$S_{hbar} = 0.34 \text{ in.}$$

The mean-failure-energy, MFE, is calculated by multiplying the mean-failure-height by the drop weight;

$$MFE = h \times w$$

$$MFE = (12.667 \text{ in.}) \times (2 \ lb)$$

$$MFE = 25.334 \text{ in}\cdot\text{lb}$$

The estimated standard deviation of the mean-failure-energy, S_{MFE}, is calculated using the following formula;

$$S_{MFE} = S_{hbar} \times w$$

$$S_{MFE} = (0.34 \text{ in.}) \times (2 \text{ lb})$$

$$S_{MFE} = 0.68 \text{ in}\cdot\text{lb}$$

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